Lior Laver
Philippe Landreau
Romain Seil
Nebojsa Popovic
Editors

Handball Sports Medicine

Basic Science, Injury Management and Return to Sport

European Society of Sports Traumatology, Knee Surgery & Arthroscopy
ESSKA

EHF

Springer

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Acknowledgments

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A Word from the ESSKA President

ESSKA's mission is to raise the level of care and achieve excellence in the field of orthopedics in Europe, especially in sports medicine and degenerative joint diseases with the intention to improve musculoskeletal function and quality of life of patients. Following this strategy, ESSKA and its newly created sports-medicine section ESMA intend to stimulate the dissemination of science to improve the health of athletes. ESSKA is proud to publish this book on handball medicine and science in its own book publishing portfolio. To the best of my knowledge, this is the first of its kind in handball and together with a book on football medicine edited by Prof. Jon Karlsson and coworkers in the same collection is part of some of the first sports-specific medical books on the publishing market. This reflects not only the increasing specialization of the sports themselves but also the growing sports-specific medical and scientific knowledge in these fields. The fact that the books are edited by orthopedic surgeons did probably not happen by accident. Despite the best surgical treatments we can offer, our community is too often confronted with situations of difficult decision-making after sports injuries, injury-related premature end of careers, or long-term physical or social consequences of sports injuries.

Therefore, I felt enthusiastic when Lior Laver approached me in 2014 at the ESSKA congress in Amsterdam to help him publishing a book on handball medicine and science. Ten years before, the massive problem of noncontact anterior cruciate ligament injuries sustained in handball had been brought up by our Norwegian friends led by Grethe Myklebust, Lars Engebretsen, and Roald Bahr [1]. They taught us that about half of these injuries could potentially be prevented by adequate prevention training. But little had changed on the handball field. Prevention exercises were still not routinely implemented in practice, and we orthopedic surgeons continued to see too many of these young patients with severe handball injuries. With the exception of Norway and some other rare places, systematic research on handball injuries was sparse until recently. One of these places was Qatar, where to the best of my knowledge the first scientific meeting on handball injuries was organized during the men's world championship early 2015. Under the leadership of Philippe Landreau and the Olympic gold medal winner of the first ever indoor Olympic handball tournament Nebosja Popovic, a large community of medical and scientific specialists with a particular interest in handball came together for a very fruitful 2-day exchange. Philippe and Nebosja developed similar plans to publish a book on medical aspects in handball. I thank them for having agreed to join us as coeditors in a single book project under the aegis of ESSKA.

Handball is one of the pivoting team sports where players are mostly affected by injuries [2]. In comparison to other sports, it can be found in the top five in terms of the number and gravity of injuries. Concussions are not rare, as are acute joint injuries, mostly of the knee and ankle, and recent studies have emphasized the importance of overload and degenerative injuries, especially of the shoulder, hip, and knee. Further research is needed to assess the magnitude of these problems, to develop preventive strategies, and to update guidelines on player safety and medical support. Despite some of the existing quality research based on handball players, the sport is lagging behind other sports when it comes to producing evidence-based medicine and science. There is lack of consistent and continuous epidemiologic data research which is necessary to improve the players' safety in an ever-changing sport environment. At the highest levels, combining national and international competitions, players play up to 80 competitive matches per year at high intensity, with plans to even increase these numbers.

Recently, the EHF has recognized the growing need to protect athletes' health. It has launched a medical and science group, aiming to identify and target immediate needs in order to improve the science in the sport as well as the medical aspects and the players' safety. It started a unique cooperation with ESSKA. Indeed, it is rare that the stakeholders of a European sports federation join forces with a scientific medical society to improve their players' health. Therefore, I thank the leadership of the EHF, and especially Mr. Helmut Höritsch, for their willingness to engage in this endeavor.

I do also thank my coeditors of which Lior Laver was the main driving force throughout the entire process and the authors, many of whom are highly recognized specialists in their respective fields, for taking their rare spare time to share their knowledge with us in this book project. In some years from now, it can be expected that the medical aspects around handball will be as thoroughly organized as in football and that the science emerging from this improved structure will be beneficial for both the sport and the players' health in the short and long run. Motivated by the numerous injuries my former teammates and I had sustained during our own handball careers, I performed one of the first epidemiological studies in handball as a young resident in orthopedic surgery [3]. Therefore, I am proud to be part of the editors' team of this book which hopefully may be beneficial to preserve or improve the health of other players.

Romain Seil

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Foreword by Michael Wiederer

As the game of handball has developed tremendously in recent years, it became evident that a structured and organized medical and scientific support for the game is needed, as well as the establishing of a continuous and productive communication between the medical and scientific aspects and the rest of the stakeholders around the game.

In 2011, the first European Handball Federation (EHF) Scientific Conference was organized by the European Handball Federation on the fringes of its 20th anniversary based on an initiative by Frantisek Taborsky, the former EHF Methods Commission Chairman, who also founded the EHF Union of University Handball Teachers (UUHT). The range of the scientific presentations was wide, including approaches from training sciences, human sciences, and sports medicine.

A quote by my predecessor and honorary EHF President, Jean Brihault, paved the way for the successful biannual continuation of EHF Scientific Conferences:

Sport, in general, and handball, in particular, needs to steep its roots in the fundamental soil of scientific knowledge, in order to progress in a controlled and responsible way towards the higher levels of performance in full respect of the individual performance.

The second edition followed in 2013, with a focus on women's handball. This edition also launched a medical symposium focusing on knee injuries in women's handball, receiving great attention.

In 2015, the third edition was fully dedicated to medical aspects of training and the game, touching on topics such as injury prevention and prophylactic training. That was only possible by the "priceless" input and support of ESSKA (European Society of Sport Traumatology, Knee Surgery and Arthroscopy) that had taken over the patronage of the conference in Bucharest (Romania), namely, Romain Seil (Luxembourg) and Lior Laver (Israel). This was the start of a unique and fruitful collaboration with ESSKA, a loyal supporter of handball and handball medicine and a natural partner to the EHF in Europe in the field of sports medicine and sports science.

Since then the ESSKA support of handball has helped to spread the medical and scientific knowledge in handball via many more handball-related medical conferences in Europe, such as in Spain (Barcelona), Sweden (Gothenburg), France (Paris), Luxembourg, and even Scotland (Glasgow).

Another important step by the EHF was the establishment of a specialists' network—The EHF Scientific Network of Specialists—in order to promote health sciences in our sport with a unique focus on the player’s environment from the grassroots to the top!

The EHF CAN (Competence Academy & Network) led by chairman Helmut Höritsch, along with the EHF Methods Commission led by chairman Jerzy Eliasz, has prepared the fourth edition of the EHF Scientific Conference in Vienna, Austria, in November 2017, with full contributions from the newly formed EHF Scientific Network of Specialists.

This book is a great example of the excellent and fruitful collaboration between the ESSKA, the EHF, and the EHF Scientific Network of Specialists. It is indeed a great and unique achievement, first of a kind in our sport and hopefully the first of many, serving not only as a comprehensive source for all medical and scientific personnel supporting handball but also as a true inspiration to what great teamwork could achieve. Congratulations to the editors and all the authors for this great work.

My personal wish is that we shall succeed in establishing a kind of medical platform of experts contributing to the sport of handball for the sake of the athletes’ health and well-being in the future. In addition, it is our aim that beach handball, a new sport of incredible value within the growing handball family, shall be made a topic of scientific research concerning medical and social aspects in the future.

The EHF is both honored and grateful for having a partner like ESSKA helping to accomplish our goals!

Wied

Vienna, Austria

Michael Wiederer

Foreword by Per Renström

The sport of team handball is rapidly growing in popularity and is constantly evolving since it was developed at the end of the nineteenth century in northern Europe and Germany. After the rules were established in 1917, the first international games were played during 1925–1930 for men in 1925 and for women in 1930. It is an accepted Olympic sport since 1972 for men and 1976 for women. The game has since then spread widely not the least in the Far East, North Africa, and South America. Lately expansions/extensions such as beach handball, mini-handball, street handball, and even wheelchair handball are rapidly attracting more and more participants worldwide. The *International Handball Federation* was formed in 1946 and currently includes 209 member federations (201 full members) under six confederations.

The game in itself has developed to be a very rapid and demanding sport, with continuous changes in the rules of the game to accommodate this evolution. These changes, along with the growing number of participants, have strengthened the constant need for proper and skillful medical coverage and attention for the team handball players. There is a great need for a relevant and reliable team handball-specific source for prevention and management of injuries and illnesses. This book will without any doubt fill that void.

The sport is often referred to as team handball to distinguish it from the individual sport of handball, popular mainly in the United States. This accentuates the importance of teamwork in a sport, where all persons involved—the players, the coaches, as well as the logistical team and the medical team—have a great responsibility. This is true not only on the field but off the field as well. Preparing a book for publication is no different and requires a great team effort. A book is as good as the authors chosen to write it.

An excellent and passionate team of four experts has come together to realize this much needed project and to edit and produce a unique achievement in the field of team handball, sports medicine, and sports science. The initiative to this book was led by Lior Laver M.D., originally from Israel and currently based in the UK. His extensive experience in team handball comes not only from his roles as a team doctor in handball and as one of the leading founders of the European Handball Federation (EHF) Scientific Network of specialists, but not the least as a professional high-level handball player, playing for the Israeli national team for many years, as well as experience in other European leagues. Coeditor Philippe Landreau, M.D., is a French orthopedic surgeon/sports traumatologist, who also has vast experience in the management of sports injuries in general and handball injuries in specific, taking care of the French women's handball team from 2004 to 2010 until he left for Qatar, where he is now the Chief of Surgery in Aspetar, one of the leading sports medicine centers in the world. The third editor is Romain Seil, M.D., Ph.D., from Luxembourg, a former handball player with strong roots in handball and handball medicine to this day, who also is an orthopedic surgeon and a leader in the world of orthopedic sports medicine and presently the President of the European Society of Sports Traumatology, Knee Surgery and Arthroscopy (ESSKA) as well as a founding member of the EHF scientific platform. The book has been carried out in cooperation with and under the scientific publication umbrella of ESSKA. The fourth and last editor is Nebojsa Popovic, M.D., Ph.D., an orthopedic surgeon, working in Qatar since 2007, previously the Aspetar Acting Chief Medical Officer and currently a senior advisor. Dr. Popovic, apart from his many years of experience as an orthopedic sport medicine expert working with teams at the highest levels, not only in handball, brings a unique perspective from being a player at the top elite level, as a world champion and winner of an Olympic gold medal with the former Yugoslavia in 1972.

The goal of the editors has been to find internationally well-known authors well experienced in medical questions in handball. They have been very successful and involved many great and respected sports medicine experts. The resulting content of the book has turned out to be very impressive with 45 chapters in total, covering every sports medicine and sports science aspect related to the game of handball. These include basic science aspects, such as biomechanics and nutrition, as well as physiologic and medical preparations in team handball. The book includes 16 chapters describing injuries, many of them specific to team handball. There are also 10 chapters dealing with prevention, rehabilitation, and preparation. The book also includes special consideration chapters dealing with female and young players, perceptual motor aspects, and antidoping. Finally, there are three chapters dealing with psychologic aspects in team handball and their association with injuries—definitely an area of growing interest. In other words, this is a very extensive and impressive book, which provides the most comprehensive educational source not only for team handball medical caregivers and scientists but for all team handball personnel. The book is made easily available and accessible to provide answers in whichever aspect of interest in handball (physicians, PTs, rehabilitation personnel, strength and conditioning trainers and coaches). The authors hope that this source would also serve as a link between the different modalities involved in team handball, creating a common language and improving communication within the team staff and environment.

This project is led by a group, who has great passion not only for the game of team handball but also a commitment to produce a book characterized by a high scientific quality and based on long experience of the medical problems of their beloved sport. With the support and collaboration of the ESSKA Publications department, the aim has been to produce a book that would be practical and innovational to improve the medical care in team handball worldwide. This book may well be a good starting point to increase the support for team handball science and improve the medical service across the whole team handball spectrum. The aim of this book is to improve players' safety and medical care in the future in parallel with the rapid evolution of the game. I would like to commend the editors and all involved to a work really well done. Congratulations.

- President ISAKOS—International Society of Arthroscopy, Knee Surgery and Orthopedic Sports Medicine 2003–2005. Vice-president 1999–2003
- Member IOC—International Olympic Committee Medical Commission 1989–2012
- Vice President FIMS—International Federation of Sports Medicine 1990–1998
- Member ATP—Association Tennis Professional and ITF—International Tennis Federation Sport Science and Medicine Commission 1997—present
- Honorary Fellowship in the Faculty of Sports and Exercise Medicine in Ireland 2007 and in United Kingdom 2011
- Inducted into the "AOSSM Hall of Fame" by the American Orthopedic Society of Sports Medicine

Stockholm, Sweden Per Renström
October, 2017

Foreword by Lars Engebretsen

Protection of the athlete is the responsibility of all of us in sports medicine.

As the head of medical science in the International Olympic Committee (IOC), it is a pleasure to see this new book on team handball sports medicine and science initiated by Lior Laver, ESSKA, and the European Handball Federation (EHF).

Surveilling the injuries and illnesses during the Olympic Games in London, Beijing, and Rio, it has become clear that team handball is a sport with a high risk of injuries (13–17% of all athletes in Beijing, London, and Rio) (Fig. 1). Although many papers on injury risk and recently on injury prevention exist, no full textbook has been available in this field. ESSKA and the authors should be proud of this new book!

The International Handball Federation was formed in 1946 and currently includes 209 member federations (201 full members) under six confederations. The game has since then spread widely not the least in Asia, Africa, and South America. Lately expansions/extensions such as beach handball, mini-handball, street handball, and even wheelchair handball are rapidly attracting more and more participants worldwide. This increase in players' numbers worldwide, along with the evolution of the game into a fast speed, intense game, brought along an increase in injuries incidence!

One of the goals of the International Federations (IF) and the National Olympic Committees (NOC) is to protect the health of the athlete. After having carried out surveillance over the last six Olympic Games and studying the published injury and illness epidemiology from the NOCs, it is evident that some IFs and NOCs are now prioritizing this work. Football, volleyball, swimming, ice hockey, and rugby are leading the IFs with excellent examples, but as this new book on medicine and science in team handball is showing, many other federations are following in their path. However, whereas some federations have made considerable resources available for well-published research teams, other federations are relying on researchers with access to grants from universities, national institutes of research, etc. This new book is a great example that excellent results may be obtained when researchers and clinicians worldwide in one International Federation get together and cooperate.

Through establishing ten Centers of Excellence, the IOC centers worldwide will provide research to protect the health of the Olympic athletes including team handball. However, the time has come for NOCs and IFs to engage in this area and introduce competitive grants. This will attract the best

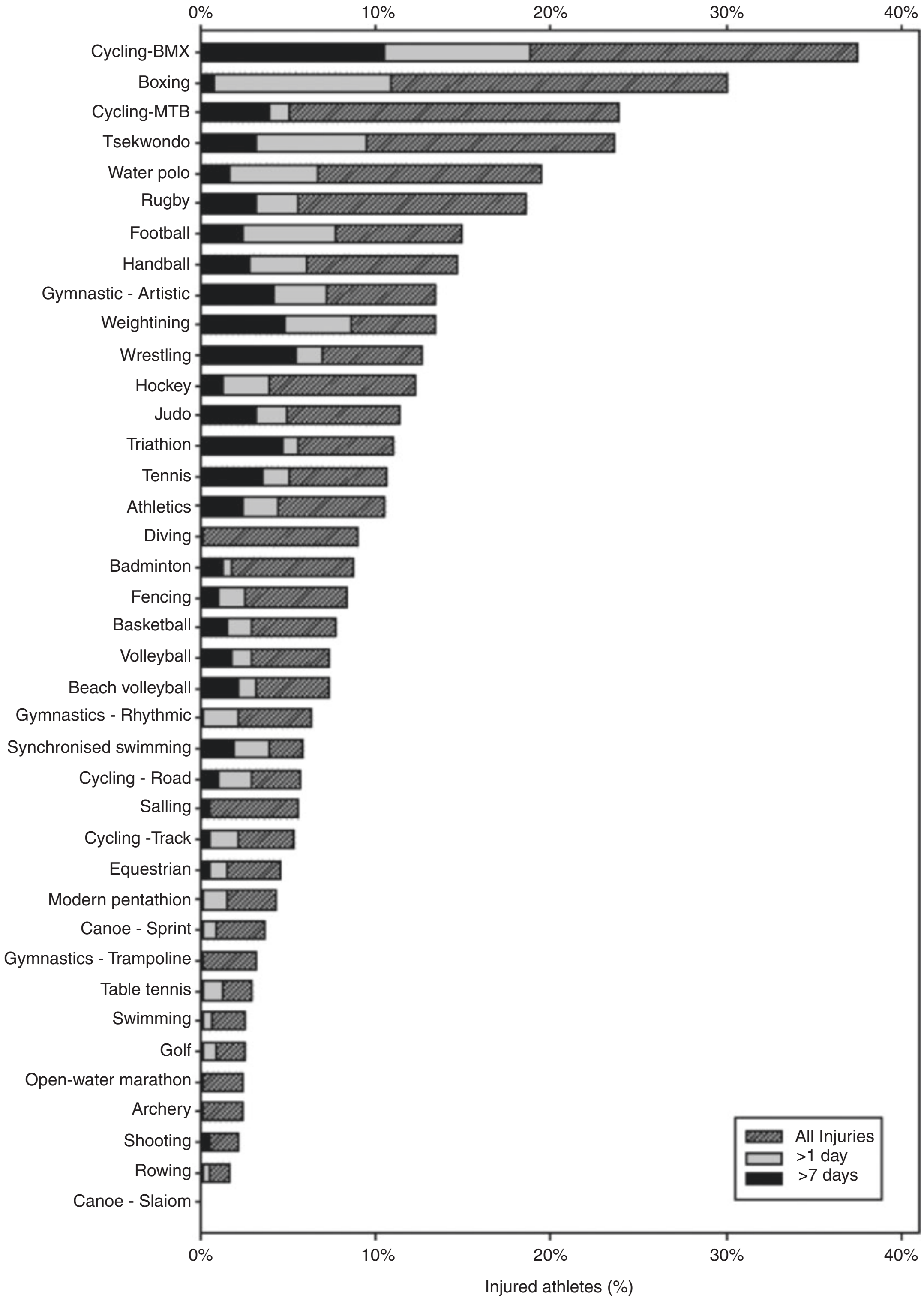

Fig. 1 Proportions of athletes (%) in each sport with injury, injury with estimated time loss >1 day, and injury with estimated time loss >7 days

researchers and secure the best protection for our athletes. Research funds are needed for work on the effect of venue and equipment modifications, training facilities and forms, rule changes, and general prevention in specific sports. The IOC surveillance of the Olympic Games has highlighted a few sports with challenges in injury prevention. Surveillance of world championships and world cups has made similar findings—the next step is to propose injury prevention protocols and then test these for their efficiency. Many IFs now have well-functioning medical commissions. It would be beneficial if the medical commissions were represented also on the IF boards. This would emphasize the importance of sports medicine for the athletes and would show the intention of the federation to prioritize work in this field.

This book provides good examples of IF work within the handball movement. The list of contributors shows a good mixture of experienced clinicians and scientists, and even better: the entire handball world is represented! Additionally, this book highlights that prevention of injuries really works. The 50% reduction in serious knee injuries obtained in Scandinavia and considerable reduction in shoulder injuries as well speak to this fact! This book should take this further!

Lausanne, Switzerland Lars Engebretsen
March 2018

Preface

The *Handball Sports Medicine Book* provides a comprehensive overview of current knowledge on the medical and scientific aspects in handball. It is a "state-of-the-art" book compiling the highest quality experts in the field and covering the entire spectrum around the medical and scientific care of handball players. The opening section discusses basic science topics such as biomechanical and physiologic aspects. The following section provides an overview of the medical preparation perimeter, discussing pre-participation assessment and screening, assembling a medical team, and medical coverage of handball events. Handball injuries and their management are extensively discussed in the third section, followed by the fourth section which focuses on injury prevention, rehabilitation, and preparation. The fifth section is dedicated to special consideration topics, such as the female player, the adolescent population, load management, doping issues, and even perceptual skills. The sixth and final section deals with psychological aspects in handball and their influence on the game.

This project hopes to affect a wide spectrum of health professionals and scientists, providing not only a source of knowledge but also stimulating and steering further scientific work and research. It will serve as a reference in the field of sports medicine, orthopedics, physiotherapy, and sports sciences.

Writing a high-quality scientific book is a challenging and demanding task. Choosing the right team for this task is crucial for its success. We can proudly say that apart from the fact that this book was written by world-renowned experts and leaders in their individual fields, all the authors brought a unique and unlimited passion to this project, which is evident in the book. We would like to thank all the authors for their time and efforts invested in this book, as well as the great passion and enthusiasm they added.

This has been produced in cooperation with the European Society for Sports Traumatology, Knee Surgery and Arthroscopy (ESSKA), and we would like to thank the ESSKA board for accepting the project in its book portfolio, the ESSKA publications team, and the ESSKA office for their support. We would like to extend special thanks to Jon Karlsson, the editor-in-chief of the *KSSTA Journal* (the journal of ESSKA) and leader of the KSSTA editorial group, for his great support and assistance. In addition to this, we would like to thank the Luxembourg Institute of Orthopaedics, Sports Medicine and Science (LIROMS) for the support in this project.

As editors, we hold a great responsibility to the wide spectrum of our target readers, to the authors in this book, to our profession, and to the sport of handball—to ensure this book is at the highest standards and that it portrays the great and excellent work invested in it. We would also like to thank our personal teams for their support. We are grateful for the help received from the European Handball Federation and Aspetar - Orthopaedic and Sports Medicine Hospital, the International Handball Federation Reference Centre for Athlete and Referee Health.

Last but not least, we would like to express our special gratitude to our families and their endless support and sacrifice allowing us to complete this task with the intended excellence.

This book brought many people together, from all ends of the "handball spectrum," to contribute and create an amazing scientific source for handball and sports medicine. We truly hope this would only be the starting point, laying the foundations of a strong network of all health and science professionals around handball and leading to many future initiatives and projects aimed to improve this amazing sport.

Coventry, UK	Lior Laver
Doha, Qatar	Philippe Landreau
Luxembourg, Luxembourg	Romain Seil
Doha, Qatar	Nebojsa Popovic

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Introduction

The sport of handball, also commonly referred to as “team handball” or “indoor handball,” to distinguish it from the individual sport of handball, is undoubtedly one of the most popular ball sports in the world. This is especially pronounced in Europe, where in many countries handball is one of the top sports in popularity and participation.

Although modern handball has only developed in the past century, with indoor handball evolving mostly in the second half of the last century, primitive forms of handball were played even in ancient times and persisted in different cultures through the middle ages and on to modern times, especially but not only in European cultures [1]. This continuous link throughout history perhaps helps explain some of the immense and ever-growing popularity of the relatively young game of modern handball as well as the fact that the modern form of the game has developed in Europe, with the “cultural gene” playing an important role.

With the evolution and growing popularity of other ball sports (football, rugby, basketball) which developed at that time, it was no surprise that three similar games have evolved almost in parallel at the turn of the last century and are considered the *direct ancestors* of modern handball:

Haanbold—Developed in Denmark by the Danish gym teacher and Olympic medalist Holger Nielsen, with the first written set of rules established in 1898 and published in 1906 [1, 2]. The first known public match took place in 1903 in Denmark.

Torball—Developed in Germany by Hermann Bachmann, with a court size similar to the current indoor size (40 × 20 m) and a goal area radius of 4 m [1].

Hazena—The Czech form of handball—Developed in Prague by Vaclav Karas in 1905 and rapidly spread toward the former Yugoslavia area, Ukraine, and Russia. Many characteristics from the game of Hazena were introduced into modern handball, such as a goal area radius of 6 m, while the court size was slightly bigger (45 × 30 m) [1].

These three games have become very popular in Europe over a short period of time, with many local tournaments throughout the continent; however, due to the different rules of each game, it was impossible to organize international competitions. The growing demand and need to unify the rules became evident, and this task was undertaken by Max Heiser, Karl Schelenz, and Erich Konigh from Germany, who published the first modern set of rules in 1917. Karl Schelenz later modified the rules in 1919. The first international games were played under these rules, between Germany and Belgium by men in 1925 and between Germany and Austria by women in 1930, also becoming an Olympic sport in 1936 in Berlin. In its early days, the game of handball or "field handball" was very different from its current form. It was an outdoor game performed on a full-size football field and based on football rules with 11 players on each team, as in football [1].

The first International Handball Federation was established in Amsterdam in 1928 as the "International Amateur Handball Federation (IAHF)," with a German and Austrian leadership in dominance. After World War II, the leadership was taken by the Scandinavians and a new association was reestablished in Copenhagen in 1946: the "International Handball Federation" (IHF). The Scandinavian leadership had an important role in the development of the game into the indoor form. Over the years, greatly attributed to the cold weather in Scandinavian countries and to its growing popularity and the demand to facilitate its availability year round, the game of handball evolved substantially since those early days and over the next decades, becoming a primary indoor game. From 1966, world championships were organized only for indoor handball (every 4 years), and this modern, indoor form of "team handball" has finally reemerged as an Olympic sport and into the front world stage in 1972 (Munich) for men and in 1976 (Montreal) for women. Since 1995, the world championships are held every 2 years for both men and women. The European Handball Federation (EHF) was founded in 1991, and European championships are held every 2 years for both men and women since 1994. Continental federations have been founded in other continents since and world and continental championships have been established for all age groups, from the junior to the senior age groups and even master age groups (for retired players).

The popularity of modern handball has enjoyed a substantial growth in recent years. In addition, the development of the game's "siblings," *Beach Handball*, *Street Handball*, and *Wheelchair Handball*, has helped spread the game even more, reaching out to all layers of the population worldwide.

Concurrently with this continual development of team handball and elite sport's increased focus on performance optimization, significant progress in the game took place with regard to parameters such as technique, tactics and intensity, as well as the physical aspect [3]. Over the years, the professional side of the sport has developed as well, side by side with the evolution of the rules of the game itself, which helped turn it into a fast and very dynamic game, contributing to its attractiveness and growing popularity. At the 2016 Olympic Games in Rio de Janeiro, handball was the second most popular team sport after football. This popularity also enjoys an equal distribution between the men's and women's game, which unfortunately is still rarely seen in other sports. These changes have also influenced the physiologic aspects of the game as well as the injury profile in the sport, which emerged as one of the most injury-prone ball sports [4, 5]. The growing need for an appropriate scientific and medical envelope to support the game became evident; however, these aspects lagged behind those provided for other popular ball sports such as football, basketball, and rugby, a fact portrayed quite distinctively in the much lower number of scientific studies and English-language scientific publications in handball compared to these other sports. Despite this discrepancy between the popularity of handball, in terms of participation and media coverage, and the science published on the sport, high-quality scientific research has been done in handball, contributing not only to the sports but providing great scientific merit for other sports as well.

The future of handball appears very bright. The IHF now counts 209 national federations among its membership (201 full members, 4 associated members, and 4 regional members) under six confederations, making it one of the biggest international sports federations. The introduction of the new discipline of *beach handball*, and even the more recent *street handball*, as well as *wheelchair handball*, which has opened a window into paralympic sports, is already helping spread the game even more, reaching out to all layers of the population worldwide. Professional leagues for men and women draw thousands of spectators in Europe, Asia, and South America, and apart from the world and continental championships for national teams, competitions such as the European champions league for men and women annually feature the world's best teams, competing for substantial prize money and international prestige. Finally, the evolution of the game of handball on all its aspects over the last century has made it the exciting, popular sport of current day. Undoubtedly, the next 100 years will bring ongoing evolution; however, the status of handball as one of the most popular and exciting sports worldwide seems to be assured. This book compiles the work of the top international experts in the field of handball medicine and handball science. It is the most comprehensive scientific source to date, aiming to aid and guide medical and all scientific personnel around the sport of handball, and hopefully will be the starting point of many other joint projects aimed to develop the medical and scientific support for the game.

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Part I

Basic and Applied Sciences

Physical Characteristics of the Handball Player

1

Ronnie Lidor and Gal Ziv

1.1 Introduction

The objective of handball is to score as many goals as possible by dribbling, passing, and throwing the ball at the goal. While one team attempts to score a goal, the opposing team attempts to block and intercept throws [1, 2]. In handball, in order to effectively execute (i.e., accurately and rapidly) offensive maneuvers either by the individual player or the entire team, as well as to be able to block offensive maneuvers performed by the opposing team, a number of specific physical characteristics, among them height and body mass, are required. It is assumed by those professionals involved in the game of handball—coaches, strength and conditioning coaches, athletic trainers, and sport physicians— that in order to achieve a high level of proficiency in this game, an "appropriate" physique or unique body characteristics are needed.

In addition, those professionals involved in training programs aimed at improving the ability of handball players should have access to information on the physical aspects of the handball players, so that they can use this information when planning short- and long-term programs for their players. For example, throughout their annual training program, elite handball players typically practice once a day on a daily basis, while during the preparation phase of the program, they may even practice twice a day. In the competition phase, elite players play at least one league game per week; in some parts of the competition phase, they play two games per week—one league game and one cup game or an international game played in international sporting events, such as a continental championship. Information on the physical characteristics of the players can be beneficial when these professionals assess the contribution of their programs to the development of the individual handball player and of the entire team.

The purpose of this chapter is threefold:

1. To review a series of studies ($N = 41$) on physical characteristics of male ($n = 21$) and female ($n = 20$) adult handball players who played in various levels of competition: national teams participating in major handball events (e.g., world championships), Division 1 (the highest division/league of competitive handball), Division 2 (the second-to-the-highest division/league competitive handball), and amateur games. Indeed, a number of previous reviews focused on the physical and physiological attributes of either male [3] or female [4, 5] handball players; however, in this chapter, we provide information on a number of physical characteristics of both male and female players.

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2. To outline a number of research and measurement concerns associated with the reviewed studies. We attempt in this chapter not only to review relevant studies on physical characteristics of male and female handball players but also to critically analyze these studies.
3. To propose a number of practical tips for the handball coach and the strength and conditioning coach who work with handball players.

1.2 Height, Body Mass, Percent Fat, and Fat-Free Mass: Descriptive Data

The reviewed studies were selected from an extensive search of the English language literature, including major computerized databases (PubMed and SPORT Discus) and library holding searches. Search terms included: *handball*, *team handball*, *handball players*, *physical characteristics*, and *physical attributes*. Forty-one articles matching our criteria were identified.

Four physical characteristics of the handball players are discussed—height, body mass, percent fat, and fat-free mass. A summary of the physical characteristics of male handball players is presented in Table 1.1, and a summary of the characteristics of female players is presented in Table 1.2. Below, each physical characteristic is discussed separately for male and female players.

1.2.1 Height

1.2.1.1 Male Players

It is assumed among coaches that taller players will perform better in game actions such as throwing the ball at the goal (an offensive maneuver) or attempting to stop a throw performed by a player from the opposing team (a defensive act). Based on the reviewed studies, it was observed that the mean height of handball players ranged from 178 ± 4.0 cm in Greek wing players who played in three teams in the Greek championship during the 2011–2012 season [6], 178 ± 9.1 cm in 12 Greek Division 2 players [7], 179 ± 4.7 cm in Greek players who played on a team that ranked 8th in Division 1 in the 2011–2012 season [8], and 179 ± 1.6 cm in 15 Kuwaiti national players [9] to 194 ± 2.1 cm in goalkeepers who played in the two top teams in the Danish premier league [10], 196 ± 9.3 cm in 25 Croatian elite line players, and 196 ± 5.4 cm in 28 Croatian elite backcourt players [11].

Information on physical characteristics of players playing different positions can help coaches match the training program to the specific attributes of players who play a similar position. When a comparison among players playing different positions was made, inconsistent data were reported. For example, in one study on 21 Tunisian national team players [12], back (193 ± 3.2 cm) and line (192 ± 7.2 cm) players were found to be taller than goalkeepers (189 ± 2.0 cm) and wing players (182 ± 4.8 cm). In another study on 46 Greek and former Yugoslavian players [13], backcourt (191 ± 6.4 cm) and line (190 ± 8.6 cm) players were taller than goalkeepers (181 ± 4.2 cm) and wing players (183 ± 6.9 cm). In a study on 92 elite player from Croatia [11], the backcourt players (196 ± 5.4 cm), the line players (196 ± 9.3 cm), and the goalkeepers (195 ± 5.2 cm) were all found to be taller than the wing players (183 ± 5.7 cm).

It was also indicated from the reviewed studies that players who played at the highest level of competition (e.g., an international level, Division 1) were taller than those who played at lower levels of competitive handball (e.g., a national level, Division 2, an amateur level) (see [7, 14, 15]). These data indicate that taller players have a better chance of playing at the highest levels than players who are not as tall.

1.2.1.2 Female Players

Mean height ranged from 164 ± 4.3 cm in 20 players participating in national and international levels of competition [16], 165 ± 4.0 cm in amateur players [17], 165 ± 4.8 cm in players from the top Spanish professional league [18], and 165 ± 6.3 cm in players from the national league in Greece [19] to 178 ± 3.4 cm in players from the 2 top-ranked teams in Danish premier league [20] and 179 ± 4.0 cm in players playing in the Norwegian national team [21].

Table 1.1 A summary of the physical characteristics of male handball players (means±SD)

Study	Participants	Height (cm)	Body mass (kg)	Percent fat (%)	Fat-free mass (kg)
Asci and Acikada [39]	Experienced players (*n* = 16)	185 ± 6.2	86 ± 8.9	N/A	N/A
Bayios et al. [7]	Greek Division 1 players (*n* = 15) and Division 2 players (*n* = 12)	Division 1: 181 ± 6.2 Division 2: 178 ± 9.1	Division 1: 83 ± 5.2 Division 2: 85 ± 12.7	N/A	N/A
Buchheit et al. [26]	National-level players (*n* = 9)	181	78	N/A	N/A
Chaouachi et al. [12]	Tunisian 2005–2006 national team players: Goalkeepers (*n* = 4), backs (*n* = 9), line players (*n* = 3), wings (*n* = 5)	Goalkeepers: 189 ± 2.0 Backs: 193 ± 3.2 Wings: 182 ± 4.8 Line players: 192 ± 7.2	Goalkeepers: 91 ± 6.8 Backs: 88 ± 8.0 Wings: 84 ± 5.9 Line players: 98 ± 12.9	Goalkeepers: 20 ± 1.4 Backs: 12 ± 3.3 Wings: 15 ± 2.8 Line players: 13 ± 2.6	Goalkeepers: 73[a] Backs: 77[a] Wings: 71[a] Line players: 85[a]
Delamarche et al. [25]	National Division 2 players and finalists of the under-18 French championship (*n* = 7)	180 ± 6.7	77 ± 7.5	N/A	N/A
Ghobadi et al. [28]	Players in the 2013 World Championship: Goalkeepers (*n* = 55), backs (*n* = 135), center backs (*n* = 55), wings (*n* = 97), line players (*n* = 67)	Goalkeepers: 191 ± 5.1 Backs: 192 ± 6.6 Center backs: 188 ± 5.9 Wings: 185 ± 5.4 Line players: 192 ± 6.3	Goalkeepers: 95 ± 10.4 Backs: 94 ± 8.2 Center backs: 89 ± 8.1 Wings: 84 ± 6.4 Line players: 99 ± 9.4	N/A	N/A
Gorostiaga et al. [14]	Elite (*n* = 15) and amateur (*n* = 15) players. Elite players were members of the Spanish handball champion team	Elite players: 188 ± 8.0 Amateur players: 183 ± 7.0	Elite players: 95 ± 13.0 Amateur players: 82 ± 10.0	Elite players: 13 ± 2.0 Amateur players: 11 ± 3.0	Elite players: 81 ± 0.09 Amateur players: 72 ± 7.0
Gorostiaga et al. [33]	Members of one elite handball Spanish team (*n* = 15), measured four times during a season: T1, first week of preparatory phase; T2, beginning of first competition phase; T3, end of first competition phase; T4, end of 2nd competition phase	188 ± 7.0	T1: 95 ± 14.3 T2: 95 ± 13.4 T3: 95 ± 12.1 T4: 93 ± 16.9	T1: 14 ± 4.2 T2: 13 ± 2.6 T3: 13 ± 2.6 T4: 14 ± 3.1	T1: 80 ± 8.8 T2: 81 ± 9.4 T3: 82 ± 8.8 T4: 80 ± 11.8
Haugen et al. [27]	Norwegian elite players (*n* = 176)	Goalkeepers: 190 ± 5.0 Backs: 189 ± 5.0 Wings: 183 ± 5.0 Line players: 192 ± 7.0	Goalkeepers: 95 ± 11.0 Backs: 89 ± 9.0 Wings: 80 ± 5.0 Line players: 100 ± 9.0	N/A	N/A
Marques et al. [37]	High-level players (*n* = 16)	184 ± 13.1	84 ± 13.1	N/A	N/A

(continued)

Table 1.1 (continued)

Study	Participants	Height (cm)	Body mass (kg)	Percent fat (%)	Fat-free mass (kg)
Marques et al. [40]	Elite players (*n* = 14), including four Portuguese international players	182 ± 6.7	82 ± 12.2	N/A	N/A
Massuca et al. [15]	Top elite (*n* = 41) and non-top elite (*n* = 126) Portuguese players	Elite players: 187 ± 5.6 Non-elite players: 180 ± 6.5	Elite players: 87 ± 10.8 Non-elite players: 80 ± 12.3	Elite players: 14 ± 4.9 Non-elite players: 16 ± 5.9	N/A
Michalsik et al. [10]	Players from the Danish Premier league. Top two ranked teams vs. entire league	Goalkeepers: Top: 188 ± 5.5 Entire: 191 ± 4.8 Wings: Top: 185 ± 5.3 Entire: 183 ± 5.0 Backs: Top: 187 ± 6.4 Entire: 189 ± 5.8 Line players: Top: 194 ± 2.1 Entire: 192 ± 4.9	Goalkeepers: Top: 94 ± 6.8 Entire: 93 ± 7.3 Wings: Top: 80 ± 5.5 Entire: 82 ± 5.5 Backs: Top: 91 ± 6.7 Entire: 91 ± 6.2 Line players: Top: 101 ± 8.3 Entire: 95 ± 7.1	N/A	N/A
Nikolaidis et al. [8]	Players from three teams that ranked 1st, 2nd, and 8th out of 11 teams during the 2011–2012 season in Greece (*n* = 44)	1st: 185 ± 6.5 2nd: 188 ± 6.1 8th: 179 ± 4.7	1st: 87 ± 9.0 2nd: 87 ± 9.8 8th: 81 ± 8.7	1st: 16 ± 3.6 2nd: 17 ± 4.0 8th: 18 ± 4.0	1st: 72 ± 5.3 2nd: 71 ± 6.2 8th: 66 ± 5.5
Nikolaidis et al. [6]	Players from three teams in the Greek championship during the 2011–2012 season (n = 39)	Goalkeepers: 188 ± 5.0 Backs: 187 ± 7.0 Wings: 178 ± 4.0 Line players: 186 ± 5.0	Goalkeepers: 88 ± 5.2 Backs: 89 ± 7.1 Wings: 85 ± 5.4 Line players: 92 ± 6.3	Goalkeepers: 18 ± 4.0 Backs: 18 ± 4.2 Wings: 15 ± 3.0 Line players: 19 ± 2.4	Goalkeepers: 72 ± 4.2 Backs: 72 ± 5.2 Wings: 64 ± 3.1 Line players: 75 ± 3.8
Oxyzoglou et al. [13]	Greek and former Yugoslavia national team players (*n* = 46): Goalkeepers (*n* = 8), wings (*n* = 14), backcourt players (*n* = 16), and line players (*n* = 8)	Goalkeepers: 181 ± 4.2 Wings: 183 ± 6.9 Backs: 191 ± 6.4 Line players: 190 ± 8.6	Goalkeepers: 87 ± 8.1 Wings: 80 ± 8.0 Backs: 91 ± 9.6 Line players: 88 ± 10.6	N/A	N/A
Póvoas et al. [30]	Participants with at least 5 years of experience in the top Portuguese league (*n* = 30)	186 ± 7.9	87 ± 8.9	9 ± 2.2	79[a]
Ramadan et al. [9]	Kuwait national players (*n* = 15)	179 ± 1.6	85 ± 3.2	11 ± 2.0	75[a]
Sporiš et al. [11]	Elite players from Croatia (*n* = 92); some of them members of the Olympic team (*n* = 22): Goalkeepers (*n* = 13), wings (*n* = 26), backs (*n* = 28), line players (*n* = 25)	Goalkeepers: 195 ± 5.2 Wings: 183 ± 5.7 Backs: 196 ± 5.4 Line players: 196 ± 9.3	Goalkeepers: 100 ± 8.8 Wings: 89 ± 6.5 Backs: 96 ± 5.4 Line players: 107 ± 7.9	Goalkeepers: 12 ± 0.6 Wings: 13 ± 3.3 Backs: 8 ± 2.0 Line players: 13 ± 6.2	Goalkeepers: 87[a] Wings: 77[a] Backs: 88[a] Line players: 93[a]

Table 1.1 (continued)

Study	Participants	Height (cm)	Body mass (kg)	Percent fat (%)	Fat-free mass (kg)
Van den Tillaar and Ettema [41]	Players from Division 2 of the Norwegian national competition (*n* = 9)	183 ± 7.0	82 ± 9.3	N/A	N/A
Van den Tillaar and Ettema [32]	Experienced players playing in Divisions 2 and 3 of the Norwegian national competition (*n* = 20)	184 ± 8.2	84 ± 10.0	16 ± 3.2	70[a]

[a]not presented in original paper—calculated by authors

Table 1.2 A summary of the physical characteristics of female team handball players (means±SD)

Study	Participants	Height (cm)	Body mass (kg)	Percent fat (%)	Fat-free mass (kg)
Bayios et al. [19]	Players from the first National League in Greece: Division A1 players (*n* = 101) Division A2 players (*n* = 121)	165 ± 0.6	65 ± 9.1	26[a]	48 ± 6.0
Ettema et al. [36]	Experienced Norwegians playing in Divisions 1–4 of the Norwegian national competition (*n* = 19)	167 ± 0.3	64 ± 7.0	N/A	N/A
Granados et al. [17]	Two handball teams participated in the study: Elite players (*n* = 16) Amateur players (*n* = 15)	Elite players: 175 ± 8.0 Amateur players: 165 ± 4.0	Elite players: 69 ± 7.0 Amateur players: 64 ± 5.0	Elite players: 20 ± 5.0 Amateur players: 23 ± 3.0	Elite players: 55 ± 4.0 Amateur players: 49 ± 3.0
Granados et al. [34]	Members of one elite team in the Spanish National 1st Division League (*n* = 16), measured four times during a season: T1, first week of preparation phase; T2, beginning of first competition phase; T3, end of first competition phase; T4, end of second competition phase	175 ± 6.0	T1: 69 ± 8.4 T2: 69 ± 7.7 T3: 69 ± 8.0 T4: 69 ± 8.2	T1: 21 ± 5.3 T2: 19 ± 5.3 T3: 19 ± 5.3 T4: 19 ± 5.4	T1: 54 ± 3.9 T2: 55 ± 4.0 T3: 55 ± 4.0 T4: 55 ± 4.2
Granados et al. [31]	National (*n* = 16) and international (*n* = 14) elite players	National: 175 ± 8.0 International: 175 ± 6.0	National: 69 ± 8.0 International: 70 ± 8.0	National: 19 ± 5.0 International: 18 ± 4.0	National: 55 ± 4.0 International: 57 ± 6.0
Hasan et al. [22]	Players from four teams participating in the 12th Asian Games in Hiroshima, Japan (*n* = 60)	Goalkeepers: 176 ± 1.9 Backs: 169 ± 2.9 Centers: 172 ± 4.4 Wings: 170 ± 8.3	Goalkeepers: 68 ± 6.3 Backs: 62 ± 2.1 Centers: 66 ± 4.5 Wings: 63 ± 7.9	Goalkeepers: 23 ± 2.8 Backs: 19 ± 2.4 Centers: 20 ± 3.0 Wings: 21 ± 2.9	Goalkeepers: 29.1 ± 2.5 Backs: 24 ± 2.3 Centers: 27 ± 1.7 Wings: 24 ± 2.5
Hoff and Almasbakk [42]	Female competitive players from one team in the Norwegian 2nd division (*n* = 16)	Training group: 171 ± 7.7 Control group: 168 ± 3.3	Training group: 70 ± 9.5 Control group: 66 ± 3.5	N/A	N/A

(continued)

Table 1.2 (continued)

Study	Participants	Height (cm)	Body mass (kg)	Percent fat (%)	Fat-free mass (kg)
Jadach and Ciepliński [43]	Players from the Polish national team; data from 1996 to 1999	1996: 174 1997: 176 1998: 175 1999: 176	1996: 67 1997: 68 1998: 67 1999: N/A	N/A	N/A
Jensen et al. [44]	Members of the Norwegian National Team (*n* = 8)	174 ± 6.7	71 ± 0.7	N/A	N/A
Mhenni et al. [29]	Players from professional clubs in the Tunisian premier league (*n* = 15)	169 ± 5.0	60 ± 8.7	24 ± 3.3	45[a]
Michalsik [23]	Danish elite players (*n* = 24)	Wing players: 169 Line players: 177 Back players: 177	Wing players: 63 Line players: 72 Back players: 70	N/A	N/A
Michalsik et al. [20]	Players from the two top-ranked teams in Danish premier league	Back players: 175 ± 5.3 Wings: 170 ± 5.0 Line players: 178 ± 3.4	Back players: 71 ± 6.1 Wings: 65 ± 2.7 Line players: 76 ± 8.1	N/A	N/A
Milanese et al. [24]	Players from four teams in the Italian national championships: Elite (*n* = 26) and sub-elite (*n* = 17) players	Elite players: 169 ± 6.04 Sub-elite players: 166 ± 5.1	Elite players: 67 ± 7.9 Sub-elite players: 64 ± 10.4	Elite players: 23 ± 5.3 Sub-elite players: 28 ± 4.0	Elite players: 47 ± 4.6 Sub-elite players: 42 ± 5.1
Noutsos et al. [45]	Adolescent players (mean age = 17.8 ± 1.2 years) (*n* = 28)	166 ± 4.7	67 ± 6.3	26[a]	53 ± 4.4
Nuviala et al. [16]	Female players participating in national and international competition (*n* = 20)	164 ± 4.3	62 ± 7.8	N/A	N/A
Ronglan et al. [21]	Training camp of the female Norwegian national team (*n* = 7) and players of the same team during international competition (*n* = 8)	Training camp: 179 ± 4.0 International competition: 176 ± 5.0	Training camp: 72 ± 6.3 International competition: 71 ± 1.8	N/A	N/A
Van den Tillaar and Ettema [32]	Experienced players playing in 2nd and 3rd divisions of the Norwegian national competition (*n* = 20)	170 ± 6.2	69 ± 8.7	28 ± 3.6	49[a]
Van Muijen et al. [46]	Well-trained players with at least 4 years of experience (*n* = 45) divided into three training groups	Control: 168 ± 6.8 Heavy training: 169 ± 4.8 Light training: 170 ± 5.6	Control: 65 ± 8.1 Heavy training: 65 ± 6.7 Light training: 65 ± 6.7	Control: 27 ± 4.0 Heavy training: 27 ± 2.5 Light training: 27 ± 2.2	Control: 47[a] Heavy training: 47[a] Light training: 47[a]
Vila et al. [18]	Players from the top Spanish professional league: Centers (*n* = 16), backs (*n* = 36), wings (*n* = 41), line players (*n* = 18), goalkeepers (*n* = 19)	Centers: 169 ± 5.3 Backs: 174 ± 6.2 Wings: 165 ± 4.8 Line players: 176 ± 8.6 Goalkeepers: 174 ± 6.3	Centers: 65 ± 6.3 Backs: 71 ± 7.8 Wings: 61 ± 4.2 Line players: 74 ± 6.6 Goalkeepers: 69 ± 7.6	N/A	N/A
Zapartidis et al. [47]	Players from the 1st division of the Greek National Championship (*n* = 16)	168 ± 8.0	62 ± 6.1	N/A	N/A

[a]Data not presented in original paper—calculated by authors

Four studies compared the height of players playing different positions. In one study on 60 players who took part in the 12th Asian Games [22], goalkeepers (176 ± 1.9 cm) and centers (172 ± 4.4 cm) were found to be taller than back (169 ± 2.9 cm) and wing (170 ± 8.3 cm) players. In a study on 24 Danish players [23], line (177 cm) and back (177 cm) players were taller than wing players (169 cm). In another study on Danish players [20], it was observed that line players (178 ± 3.4 cm) were taller than back (175 ± 5.3 cm) and wing (170 ± 5.0 cm) players. Finally, among professional Spanish players [18], line players (176 ± 8.6 cm), goalkeepers (174 ± 6.3 cm), and back players (174 ± 6.2 cm) were found to be taller than centers (169 ± 5.3 cm) and wing players (165 ± 4.8 cm).

As was observed in the studies on male players, female players who played at the highest levels of competition were found to be taller than those who played at lower levels (see [17, 24]).

1.2.2 Body Mass

1.2.2.1 Male Players

Mean body mass ranged from 77 ± 7.5 kg in 7 national Division 2 players and finalists of the under-18 French championship [25] and 78 kg in 9 national-level players [26] to 100 ± 8.8 kg in 13 Croatian goalkeepers [11], 100 ± 9.0 kg in Norwegian line players [27], 101 ± 8.3 kg in elite Danish players [20], and 107 ± 7.9 kg in Croatian line players [11].

When mean body mass was measured in players playing different positions, it was reported that line players were heavier than goalkeepers, back players, and wing players. For example, in a study on players who played for the Tunisian national team [12], line players (98 ± 12.9 kg) were found to be heavier than wing players (84 ± 5.9 kg), back players (88 ± 8.0 kg), and goalkeepers (91 ± 6.8 kg). In another study on players who participated in the 2013 World Championship [28], line players (99 ± 9.4 kg) were heavier than wing players (84 ± 6.4 kg), center back players (89 ± 8.1 kg), and back players (94 ± 8.2 kg). Finally, in a study on Greek players who played in Division 1 [6], line players (92 ± 6.3 kg) were heavier than wing players (85 ± 5.4 kg), goalkeepers (88 ± 5.2 kg), and back players (89 ± 7.1 kg). In only one study—on Greek and former Yugoslavian players [13], backcourt players (91 ± 9.6 kg) were heavier than line players (88 ± 10.6 kg).

1.2.2.2 Female Players

Mean body mass ranged from 60 ± 8.7 kg in 15 players who played in the Tunisian premier league [29], 61 ± 4.2 kg in 41 wing players from top Spanish professional league [18], 62 ± 2.1 kg in international back players [22], and 62 ± 7.8 kg in national and international players [16] to 76 ± 8.1 kg in Danish line players [20], 74 ± 6.6 kg in Spanish line players [18], and 72 kg in Danish line players [23].

Similar findings were observed when body mass was compared among players playing different positions: line players were heavier than players who played in other positions. For example, in a study on elite Spanish players [18], line players (74 ± 6.6 kg) were heavier than back players (71 ± 7.8 kg), goalkeepers (69 ± 7.6 kg), centers (65 ± 6.3 kg), and wing players (61 ± 4.2 kg), and in a study on Danish players [23], line players (72 kg) were heavier than back (70 kg) and wing (63 kg) players.

1.2.3 Percent Fat

1.2.3.1 Male Players

Percent body fat ranged from 8 ± 2.0% in 28 Croatian backcourt players [11], 9 ± 2.2% in 30 players with at least 5 years of experience in the top Portuguese league [30], and 11 ± 2.0% in 15 players from the Kuwait national team [9] to 20 ± 1.4% in 4 Tunisian national goalkeepers and 19 ± 2.4% in Greek line players [6].

In three studies where a comparison of percent body fat among players playing different positions was performed, mixed results were reported. For example, in a study on Tunisian players [12], percent body fat was higher in goalkeepers (20 ± 1.4%) than in wing (15 ± 2.8%), line (13 ± 2.6%), and back (12 ± 3.3%) players, while in a study on elite players from Croatia [11], percent body fat was higher in line players (13 ± 6.2%), wing players (13 ± 3.3%), and goalkeepers (12 ± 0.6%) than in backcourt players (8 ± 2.0%).

1.2.3.2 Female Players

Percent body fat ranged from 18 ± 4.0% in 14 international players [31], 19 ± 2.4% in Asian back players [22], and 19 ± 5.0% in national players [31] to 28 ± 4.0% in 17 sub-elite Italian players [24] and 28 ± 3.6% in 20 experienced players playing in the Norwegian Divisions 2 and 3 [32].

In one study on players of different positions [22], percent body fat was higher in goalkeepers (23 ± 2.8%) than in wing players (21 ± 2.9%), centers (20 ± 3.0%), and back players (19 ± 2.4%).

1.2.4 Fat-Free Mass

1.2.4.1 Male Players

Fat-free mass was measured in only eight out of the 21 reviewed studies on male players. In these studies, fat-free mass ranged from 64 ± 3.1 kg in Greek wing players [6] and 66 ± 5.5 kg in Greek players who played for a team that was ranked eighth in Division 1 [8] to 88 kg and 87 kg in Croatian backcourt players and goalkeepers, respectively [11], and 85 kg in Tunisian line players [12]. It was concluded in these studies that a high body mass, and specifically high fat-free mass, is advantageous in handball. Since fat-free mass data were not available in the studies by Chaouachi et al. [12] and Sporiš et al. [11], the presented fat-free mass values were calculated by the authors.

In the three studies where fat-free mass was compared among players playing different positions [6, 11, 12], it was observed that fat-free mass was higher in line players than in back players, wing players, and goalkeepers. For example, in Sporiš and colleagues' [11] study on elite Croatian players, fat-free mass was higher in line players (93 kg) than wing players (77 kg), goalkeepers (87 kg), and backcourt players (88 kg).

1.2.4.2 Female Players

Among the 20 studies on female players, fat-free mass was measured in only ten. Fat-free mass ranged from 24 ± 2.3 kg in Asian back players and 24 ± 2.5 kg in Asian wing players [22] to 57 ± 6.0 kg in international players and 55 ± 4.0 kg in national players [31].

In only one study was fat-free mass measured in players playing different positions [22]: fat-free mass was higher in goalkeepers (29 ± 2.5 kg) and centers (27 ± 1.7 kg) than in back (24 ± 2.3 kg) and wing (24 ± 2.5 kg) players.

1.3 Changes in Physical Characteristics Throughout the Season

In most of the studies reviewed in this chapter, physical characteristics were measured only once during the season. Changes in physical characteristics throughout the entire season were examined in only two studies. In one study on 15 male members of one elite team in Spain [33], physical characteristics were assessed four times during the season—the first week of the preparation phase, the beginning and the end of the first competition phase, and the end of the second competition phase. No differences in body mass or percent body fat were indicated. Indeed, fat-free mass increased slightly throughout the season, however returned to baseline values by the end of the second competition phase.

In a second study on 16 elite Spanish female players [34], a similar protocol that had been used by Gorostiaga et al. [33] was applied: data were collected four times throughout one season—during the first week of the preparation phase, at the beginning and at the end of the first competition phase, and at the end of the second competition phase. Percent body fat decreased and fat-free mass increased by approximately 2% from the first week of the preparation phase to the end of the first competition phase. This finding suggests a possible positive effect of the strength and conditioning program throughout the season. However, it should be noted that these differences were estimated from skinfold measurements, which can produce error rates of more than 2% (see, e.g., [35]), and therefore it is unclear whether these differences represent actual improvement.

1.4 Research and Measurement Concerns

Three concerns associated with the nature of the reviewed studies are discussed:

1.4.1 Small Sample Size

In a number of studies, particularly in the studies that examined physical characteristics in elite handball players (e.g., [7, 36, 37]), the sample of the players was quite small. In order to obtain a broad picture of the physical characteristics of the male and female players, data should be collected on additional samples of high-level players. If coaches are considering using the data presented in some of the reviewed studies, a cautious approach should be adopted.

1.4.2 Limited Number of Longitudinal Studies

In only two studies [14, 33] out of the 41 studies reviewed in this chapter did the data collection process last throughout the entire season (a number of months). In most of the studies, a longitudinal approach was not adopted by the researchers. By using a longitudinal approach, relevant information on the development of the physical characteristics of the handball player can be collected, analyzed, and interpreted. It would be useful for researchers and practitioners alike to gather information on body mass, percent fat, and fat-free mass throughout different phases of the entire season—the preparation phase, the competitive phase, and the transition phase—as well as across a number of seasons. This information would result in improving the training programs developed for the adult handball player.

1.4.3 Lack of Manipulative Studies

Most of the studies reviewed in this chapter are of a descriptive nature and did not include manipulative studies, such as studies examining physical characteristics (i.e., body mass and percent body fat) of players of different levels of experience (players who play on the first team versus substitute players or players who are playing their first-ever season in a given division versus players who have experienced playing a number of years in this division) or players of different age categories within the team (e.g., the younger players versus the veteran players on the team). The descriptive nature of most of the studies does imply certain possible conclusions. However, by no means can these suggest actual causality. The knowledge that emerged from the manipulative studies can be used to help coaches assess the contribution of different programs to the development of their players, as well as to better match the program to the specific needs (e.g., lack of experience, lack of playing time) of the individual player.

1.5 Practical Suggestions for Handball Coaches and Strength and Conditioning Coaches

Based on the findings that emerged from previous studies, four practical tips are proposed for the handball coach and the strength and conditioning coach:

- *A Systematic Collection of Data*

Since the handball season lasts a number of months, it is recommended to systematically gather information on relevant physical characteristics of the handball player. Of particular interest for the handball coach and the strength and conditioning coach are changes in body mass and percent fat in certain situations, such as when the player is not provided with enough playing time during league games or when he or she is coming back from injury. Changes in body mass and percent fat should be recorded in order to assist coaches in developing an appropriate practice regime for the given player.

- *The Use of Individual Data*

In the studies reviewed in this chapter, means and standard deviations are typically presented for each of the physical characteristics. However, coaches are recommended not only to rely on these means and standard deviations but also to take into account the individual data of all players on the team to better assess their physical profile and in turn to select the most appropriate activities/drills for each player. The better the match between the training program and the needs/preferences of the individual handball player, the higher the chance that the player will benefit from the specific training program.

- *The Use of Data on Physical Characteristics of Adult Players in Talent Detection and Early Phases of Talent Development*

Indeed, in this chapter we review the physical characteristics of the adult handball player. However, these data can be used by coaches who are searching for talent in handball, as well as by those who work with players in the early phases of talent development (e.g., throughout the first 5 years of practice). Information on the physical characteristics of the adult player can assist these coaches, for example, in selecting a preferred playing position for a young player, as well as in planning his or her task-specific training program.

- *The Creation of Big-Data Files*

In order to enhance the decision-making processes of handball coaches when they are planning annual short- and long-term training programs or preparing their players for actual games, big-data files should be created (see, e.g., [38]). These files should be composed not only of box-score performance data and scouting reports but also of medical reports where information on physical characteristics such as height, body mass, percent fat, and fat-free mass is included. An analysis of the interrelationships among the physical characteristics of the players, as well as other variables related to their performances in practice sessions and games, will assist coaches in better assessing the effectiveness of the training programs and the contribution of these programs to the player's professional development.

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2

On-Court Physical Demands and Physiological Aspects in Elite Team Handball

Lars Bojsen Michalsik

2.1 Introduction

Modern team handball match-play imposes substantial physical demands on elite players. However, only relatively limited knowledge seems to exist about the specific on-court working requirements in elite team handball. Thus, the overall purpose of this chapter is to give a brief overview of the present knowledge about the on-court physical demands placed on adult male and female elite team handball field players in relation to playing positions. In addition, it is also the aim to characterise the physiological aspects in elite team handball and to present an outline of the potential differences in the on-court physical demands in male vs. female adult elite team handball match-play. The activity pattern of goalkeepers is very much specialised and differs substantially from those of field players, and a description of the physical demands placed on goalkeepers is not included in this chapter. Gaining increased knowledge about the physical demands in elite team handball and the physiology of elite players provides the basis for improving the design, planning and implementation of optimal physical training in elite team handball players to increase playing performance and reduce fatigue and the number of overload injuries.

2.2 The Physical Demands and Physiological Profile of Elite Team Handball Players

Team handball is an Olympic sport (in its current form since 1972 for men and 1976 for women) that has shown increasing worldwide popularity over the last decades. It is played professionally in a large number of mainly European countries, and major international championships are held regularly. Team handball is an intense physical game, and occasionally it can be a highly rough game. Despite this, great muscular strength and well-trained physique alone is not a sufficient background to perform well in elite team handball. Rather, these factors must be complemented by a variety of technical and cognitive skills including tactical understanding as well as an ability to optimally utilise the distinct physique of the individual player and the interaction of the players on the team.

Especially through the last 30 years, team handball has undergone a major development from a relatively slow ball sport into a more dynamic game with high speed and intensity including a great amount of physical confrontations between players. In addition, the rules in recent years have been changed and adapted, so team handball has

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emerged into an exciting and very speedy ball game. Thus, modern team handball is often referred to as a rapid transition game, as players frequently switch between defensive and offensive play. Not surprisingly, the marked alterations in rules during recent years have contributed to changing the physical demands placed on the players. Consequently, present-day team handball is a faster and more physically demanding game with a substantially higher number of attacks and goals per match [1]. Furthermore, especially male players have, e.g. become bigger in size and more well-trained compared to the past [2].

Playing performance in team handball is determined by the players' technical, tactical, psychological/social and physical characteristics, which comprise a wide array of elements (see Fig. 2.1). All these elements are of high importance and also closely interlinked, making team handball a particularly complex sport. For example, a high level of physical conditioning is required, if elite team handball players should be able to exploit their technical and tactical qualities during an entire game [3]. Likewise, if a player's tactical skills are deficient, the technical quality of the player may not be fully utilised.

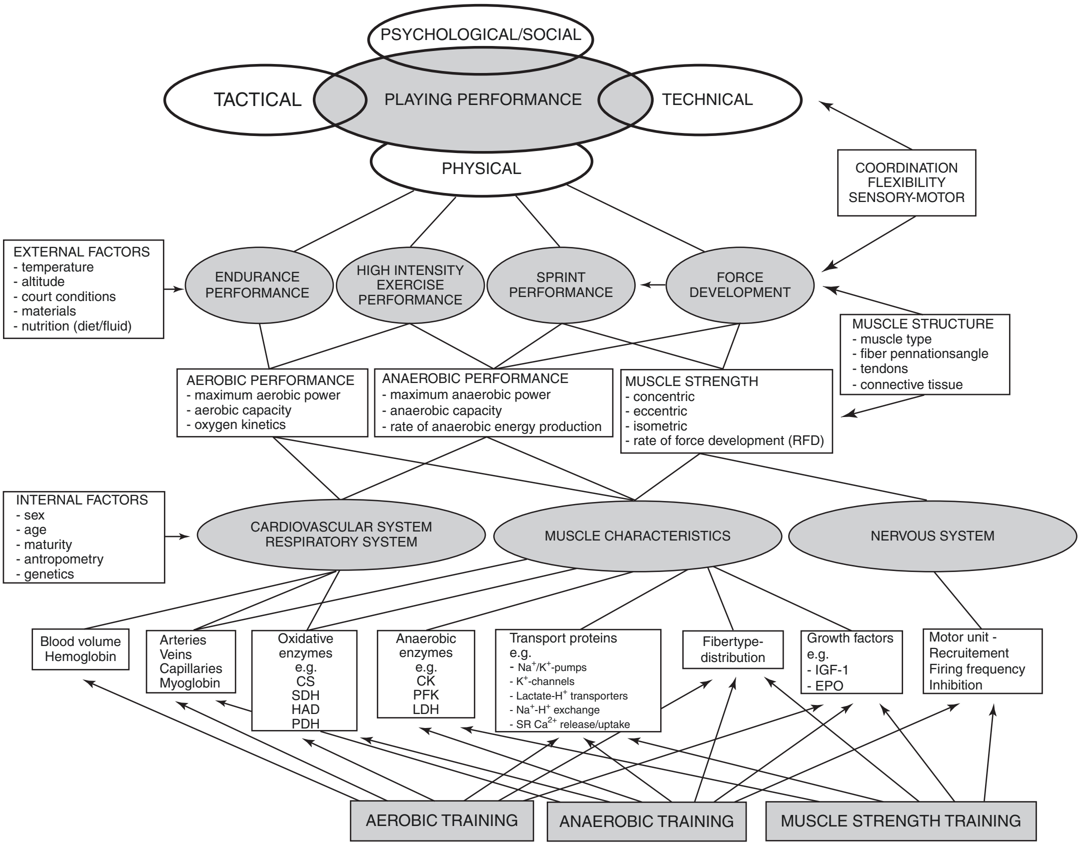

Fig. 2.1 A model of the relationship between the various factors that contribute to playing performance in team handball with special reference to the physical characteristics. Team handball playing performance is determined by the technical, tactical, psychological/social and physical capacities of each individual player. These various areas overlap and influence each other. The physiological factors can be divided into several match performance abilities (upper part). These abilities are dependent on variables, which can partly be evaluated separately (middle part). The capacity of the cardiovascular and respiratory system, muscle characteristics and neural factors constitute the basic components of the physical performance that are determined by genetic factors and training status (lower part). Performance during match-play is also influenced by various external factors, including environment and nutrition

During team handball match-play, players perform various activities ranging in intensity from standing still or walking to maximal intensity during, for example, sprint running and maximal ball throwing. The intensity can alternate at any given time, making team handball an intermittent type of sport. This distinguishes team handball from sports like rowing and marathon running, where continuous exercise is performed with either high or moderate intensity throughout the entire event. Consequently, the physical demands in team handball are more complex than in many individual sports. The physical demands, required from a team handball player, can be divided into the following categories (see Fig. 2.1):

- The ability to perform prolonged (2 × 30 min) intermittent exercise (endurance), including the ability to repeatedly recover from short-lasting, high-intensity playing actions
- The ability to exercise with high intensity
- The ability to sprint
- The ability to develop great strength and high-power output and to coordinate movements in match situations such as passing, shooting, jumping, changing direction and tackling

The basis for performance within these categories is provided by the specific characteristics of the cardiovascular and respiratory systems and the muscles, combined with the interaction with the nervous system (see Fig. 2.1). These characteristics are primarily determined by genetic factors, but they may also, to a large extent, be developed by training. Performance during match-play is dependent on gender, age and maturity and is also influenced by various external factors, including environment, materials (e.g. the ball and team handball shoes), injuries and nutrition (see Fig. 2.1).

Analysing team handball is highly complicated, not only because the game is multifactorial, but also because it is determined by both the individual performance of each player and the tactical components and interindividual interaction of the team (see Fig. 2.2). As a team ball sport, team handball is strongly influenced by tactical concepts in offence and defence as well as social/mental factors within and outside the team.

Even compared to soccer, the most popular and widespread ball game in the world, team handball is more diverse. It involves considerably more physical confrontations with opponent players, and the players are more deadlocked in different playing positions, which probably lead to specific requirements of each playing position. The game is further complicated by the fact that unlike in soccer, team handball rules allow an unlimited number of player substitutions through-

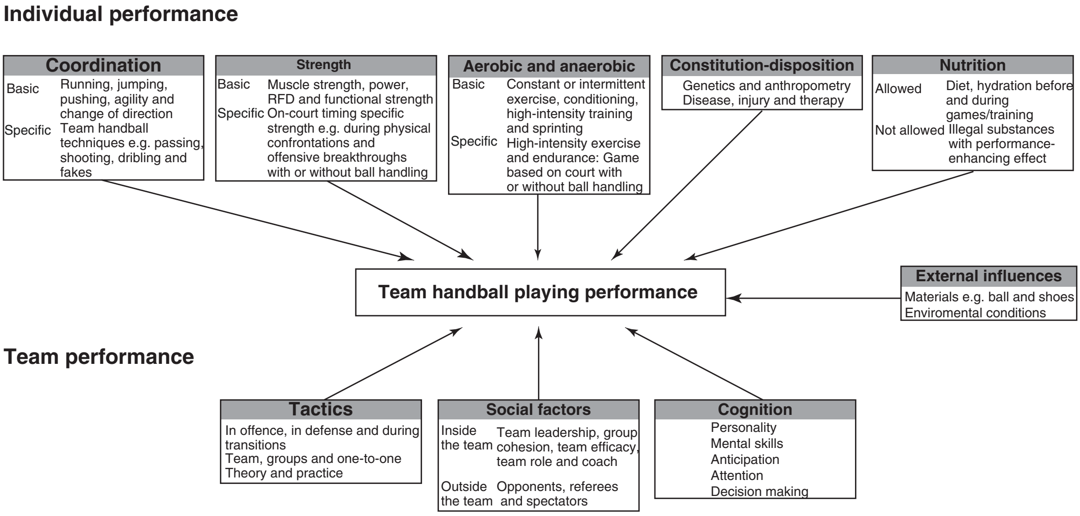

Fig. 2.2 Determinants of individual and team performance influencing team handball playing performance as a whole

out the entire course of the match. Thus, for mainly tactical reasons, some players are substituted and rotate between each transition of ball possession, i.e. some players specialise playing in offence only, while others play only in defence.

Finally, since substitutions can occur at any time during a match, these may be used as an important part of the adjustment of the physical load in various stages of team handball match-play. Apart from the tactical considerations, this may enable players to sustain a high intensity and a high level of playing performance throughout the entire match. However, such substitutions need to be considered thoroughly, especially if the performance qualities of the substitutes are lower.

The physical demands in team handball seem to reflect a complex interaction between many types of activities, including muscle strength and power, speed, anaerobic work capacity as well as aerobic power and endurance. Team handball players have to master a multitude of these categories in order to be successful. However, strengths and weaknesses probably can, to some extent, compensate for one another, both at the team level and for the individual player. In most cases, elite team handball players have a high capacity only within some of the physical categories.

From a physical point of view, the success of a team depends on selecting the right players for the various playing positions and developing a tactical approach that fits the strengths of the available players. Thus, a high level of physical capacity in some areas may not be crucial for playing at top-level. For example, a player may compensate for low endurance by having high capacities in other aspects relevant to team handball, e.g. great muscle strength or high technical standard. However, this may depend on the playing position and additionally requires that other players in the team can compensate for this deficiency by having a high endurance capacity. The applied tactical systems and individual tasks can vary both during and between consecutive games due to strategic adjustments and will influence the activity pattern of the players. Furthermore, the rotation strategies of specialised players at the elite level will likely have a significant effect on number of match activities and on the potential development of fatigue.

As the game of team handball has evolved substantially over the last few decades, the on-court requirements have increased and are especially high for elite male and female players. The increasing number of matches and national/international tournaments has led to an extension of the competition period, now covering 9–10 months per year, where elite players are required to perform constantly at a high level despite the effects of their hard training and match schedules. At the elite level, during the season, it is often common to have two matches per week compared to one at lower levels of play, and in various periods elite players often train twice a day [4].

Therefore, the physique of top-level team handball players has a governing influence on playing performance not only during each game throughout the entire regular season, but especially in various international tournaments, where multiple matches are played over a short period of time. Moreover, during the last decade, new rule changes have contributed to elevating the intensity of match-play and increasing the physical demands placed on present-day players.

2.2.1 Match Analysis of Adult Elite Team Handball

With this development in mind, there is an increasing need to develop and implement optimal physical training regimes in elite team handball that can be used to enhance players' performance, improve recovery, reduce fatigue and limit the risk of overload injuries. To establish such training regimes, it is a precondition to be thoroughly versed in the exact on-court requirements for present-day elite players. Such prior knowledge of the working demands, combined with practical experience, provides the needed basis for the identification, planning and execution of effective training paradigms [5].

Despite the considerable global spread of the sport, the amount of published studies on the physiological aspects of the game of team handball are still limited compared to other ball games like soccer, rugby, volleyball and American football. Moreover, many of the studies are of an earlier date, and thus the latest developments in the team handball are not taken into account [6–13] although significantly more studies have begun to be published in recent years [14–27]. However, these studies and most of the other new studies are dealing with training interventions, other aspects like testing and testing methods or only focusing on junior players [28–41]. Furthermore, they are mostly performed with male players.

Various technical and tactical reports concerning, e.g. the amount of attacks, shots, goals, fast breaks, ball possessions and passes are provided by national federations (federation online archives) and also described in team handball-specific journals. Moreover, the European Handball Federation (EHF) and the International Handball Federation (IHF) have published detailed statistics for every final round of the Olympic Games, World and European Championships in the last 15 years for national teams as well as the EHF Champions League for club teams. Some of these observations can be used partly as information to shed light on the physical demands of the game. However, it must be recognised that these reports are not published in peer-reviewed journals, and in almost every case the methods for providing the data are not disclosed. Additionally, such reports mostly comprise national team tournaments, where many matches are played in a short time period (8–10 matches in 10–14 days). This does not reflect the regular season scenario (1–2 matches per week), which will change the physical load and the activity pattern of the players due to less recovery time between the matches [1].

2.2.2 Methodology

The most common analysis method of the on-court physical demands is time-motion analysis based on video player observations of competitive games. The videotapes are replayed on a monitor for computerised coding of the activity pattern of each individual player. By continuously following and assessing the separate actions during the match on a video monitor, each either locomotive or technical playing action can constantly be registered by a designated software. However, this analysis method is highly time-consuming. Furthermore, it has some limitations, since it is influenced by subjective assessments by the observer and does not actually measure the precise locomotion speed.

In addition, a Portuguese study [42], e.g. aimed to determine the physical demands in male elite team handball by collecting data using video recording from the playing position and not from individual players. Thus, when a player was substituted, the substitute on the same playing position was recorded. However, the average result from the playing position (60 min playing time) will then depend highly on the substitution frequency, because substituted players most likely will show an atypically high playing intensity. Consequently, it is very difficult to compare the results within the same playing position and also to all other playing positions. Therefore, by using such time-motion procedure, the average results will not reflect the actual demands for elite players during team handball match-play. Thus, more precise analysing systems are needed in team handball.

Recently, a techno logical analysing system has been developed, which enable measurement of the actual locomotion speed of the players and in addition can account for all changing actions, i.e. accelerations and decelerations, that occur during match-play even when the speed is low. The matches are recorded using a three-camera setup in order to gain full coverage of the court [43]. As a result, the players are not required to wear a device, and the system is able to capture both playing teams. However, the system is adapted from soccer, but continues to measure the activities when the players are on the court even when the time is stopped due to brief match pauses during, e.g. suspensions, penalties, timeouts and injuries. This temporal extension compared to a normal match total effective playing time of 60 min can easily last 10–15 min. Consequently, the results from studies using this analysing method (e.g. [43]) cannot be used as scientific documentation of the physical demands in elite team handball.

In the last decade, the time-consuming challenges of video based time-motion analysis have been circumvented by the development and the application of global positioning systems (GPS) based on satellite technology into the sporting environment [44, 45]. However, at present GPS based methods are only applicable to outdoor sports and are primarily used in studies of, e.g. soccer, rugby and Australian football. In recent years, inertial measurement units (IMU) have been integrated into GPS devices, to provide additional information relating to physical loads during matches and training in ball games. Information from IMUs are independent of GPS signals. Thus, they can be used in indoor environments (as well as outdoors).

Several Norwegian studies have recently used IMUs to analyse the locomotive activity pattern of female elite team handball players during training and match-play [46–49]. Each player was equipped with an IMU, which was located between the shoulder blades in a custom-made vest worn under the player's match jersey. Data of accelerations, decelerations and changes of direction (in total high-intensity events) and the overall intensity per min (player load) were collected. The system proved to be reliable and very precise to direct measurement of high-intensity activities. However, IMUs cannot measure the technical playing actions and, e.g. the total distance covered. In addition, the players have to wear a device, which means that interference in the team's preparation to competitive matches will have to take place. Moreover, at present it is not allowed to wear such devices during elite team handball matches. There is currently no ideal analytical method that can accurately measure the on-court physical requirements for elite team handball players.

2.2.3 On-Court Study Results

Few studies have actually examined the on-court physical and physiological demands during competitive adult match-play for field players especially in relation to playing position. Recently, a series of studies of the on-court physical demands in both male and female adult elite team handball was conducted [2, 3, 5, 50–52]. Male and female adult elite team handball field players from the Danish Premier Male vs. Female Team Handball League were examined during match-play using video-based computerised locomotion and technical analysis of competitive matches during six and five regular match seasons for male and female elite players, respectively.

These analyses comprised assessment of locomotion characteristics (running types, intensity and distance) separated in distinct locomotive categories, while technical match activities were distributed in major types of playing actions (shots, breakthroughs, fast breaks, technical errors, defensive errors and tackles) and further divided into various subcategories (e.g. type of shot, hard or light tackles, claspings, screenings and blockings). This applied for field players who were divided into three categories, wing players, pivots and backcourt players, respectively, and analysed separately in offence and in defence.

The studies demonstrated substantial positional differences in physical demands, with wing players demonstrating a more intensive locomotive activity pattern and performing less physical confrontations with opponent players than backcourt players and pivots in both genders (for selected technical playing actions, see Table 2.1).

Players with limited on-court playing time (≤70% of full match duration) were excluded from the mentioned time-motion analysis, because the studies aimed to only include players with sufficiently long field playing time (≥70% of full match duration) to ensure that their activity pattern would adequately reflect the overall physical demands of the game. In elite team handball, there are players, who are specialised to play only in offence or only in defence, typically spending much less than 70% of full playing time on the match court. This also applies to second-choice players, who are not in the team's starting line-up and only are substituted onto the playing court for brief periods later in the match. A pilot study showed that such players (playing for, e.g. 15–20 min) had a more intense activity pattern compared to players who were involved

Table 2.1 Examples of the significant positional differences for male elite team handball players [3]. The offensive and defensive technical playing actions per match (group mean ± SD) for all players combined and for the different playing positions, respectively, are shown. The differences in the amount of tackles are highlighted

Offensive actions in total for the entire match positional differences				
	All players combined ($n = 82$)	Wing players ($n = 23$)	Pivots ($n = 18$)	Backcourt players ($n = 41$)
Playing actions	Number per match	Number per match	Number per match	Number per match
Playing time (min)	26.18 ± 3.13	26.52 ± 3.55	26.12 ± 2.68	26.02 ± 3.10
Offensive breakthroughs	1.5 ± 1.4	1.2 ± 1.2	1.0 ± 0.5	1.8 ± 1.3
Fast breaks	6.0 ± 4.2	8.9 ± 3.1*	8.3 ± 4.0	3.4 ± 3.2$^{\pi}$
Technical errors	1.5 ± 1.3	1.2 ± 0.9	1.6 ± 1.2	1.5 ± 1.7
Hard tackles	7.5 ± 4.4	4.3 ± 2.1*	11.6 ± 3.2$^{\#}$	7.5 ± 2.7$^{\pi}$
Light tackles	27.0 ± 18.4	10.6 ± 2.3*	58.9 ± 20.3$^{\#\#}$	22.2 ± 10.0$^{\pi\pi}$
Claspings	2.7 ± 1.9	1.2 ± 0.9	6.1 ± 2.9$^{\#\#}$	2.1 ± 1.5$^{\pi\pi}$
Screenings	4.8 ± 8.3	0.4 ± 0.7*	16.7 ± 9.6$^{\#\#}$	2.2 ± 4.3$^{\pi\pi}$
Shots	8.5 ± 4.2	6.0 ± 2.5***	7.0 ± 2.0	10.5 ± 3.4$^{\pi}$
Scoring percentage	44.9 ± 17.7	46.9 ± 23.9	48.8 ± 24.2	42.0 ± 14.6
Defensive actions in total for the entire match Positional differences				
	All players combined ($n = 82$)	Wing players ($n = 23$)	Pivots ($n = 18$)	Backcourt players ($n = 41$)
Playing actions	Number per match	Number per match	Number per match	Number per match
Playing time (min)	27.67 ± 4.18	26.28 ± 2.40*	27.08 ± 2.42	28.70 ± 2.80
Hard tackles	5.8 ± 3.6	4.9 ± 3.3	6.6 ± 3.2	6.0 ± 3.3
Light tackles	24.1 ± 12.6	14.6 ± 5.9*	33.7 ± 12.4$^{\#\#}$	25.2 ± 7.3$^{\pi}$
Claspings	3.9 ± 3.0	1.3 ± 1.1**	8.2 ± 5.0$^{\#\#}$	3.5 ± 2.0$^{\pi}$
Screenings	6.1 ± 3.1	0.9 ± 1.5****	12.4 ± 7.4$^{\#\#}$	6.3 ± 3.7$^{\pi}$
Blockings	3.7 ± 3.5	0.2 ± 0.4****	5.5 ± 3.2$^{\#\#}$	4.9 ± 2.8
Defensive errors	3.8 ± 2.5	3.0 ± 2.2	5.4 ± 1.8$^{\#}$	3.7 ± 2.3

Difference between wing players and backcourt players $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.005$ and $^{****}p < 0.001$, between wing players and pivots $^{\#}p < 0.05$ and $^{\#\#}p < 0.001$, between pivots and backcourt players $^{\pi}p < 0.05$ and $^{\pi\pi}p < 0.001$

for longer durations of the game. Including players with much reduced on-court playing time in the analysis may dilute the analysis of the best players. On the other hand, it definitely seems of high relevance to conduct future studies in order to examine the physical requirements of such 'specialised' team handball players with short effective playing time to provide valuable information about rotation/substitution strategies in elite team handball match-play.

In a study conducted at the 2007 Men's World Cup [53], substantial differences in the locomotive characteristics were also found to exist between various playing positions. The study showed a much higher percentage of high-intensity running compared to Michalsik et al. [3], which may be partly due to a lower mean individual effective playing time of ~30 min. These data suggest that in international male elite team handball tournaments where each team plays 8–10 matches in 12–14 days, players tend to be frequently substituted on all playing positions. However, the study was only published as an abstract, and thus the study method, including the definitions of the locomotive categories, was not fully described.

Manchado et al. [54] studied the on-court physical demands of female elite team handball players in two matches using the Sagit match analysis system (validated by Pers et al. [55]).

Total distance covered (5250 m) and the amount of high-intensity running for field players was markedly higher compared to Michalsik et al. [5]. This may be due do the very limited number of matches and especially different analysing procedures, since the locomotion activity was calculated for all field players in one position for the entire match duration. Moreover, in contrast to the studies of Michalsik et al. [5] and Luteberget and Spencer [47], no significant positional differences were detected between female field players. Field players with a higher level of VO_2-max executed locomotion activities with a higher velocity as compared to players with lower aerobic performance, independent of playing position. In addition, the acceleration profile depended on aerobic performance and field playing position. The authors concluded that a high VO_2-max appears to be important in top-level female elite team handball, which is in accordance with other studies [5, 52].

Using IMUs, Luteberget and Spencer [47] demonstrated a high occurrence of high-intensity events (HIEs, intensity ≥2.5 m/s) with marked positional differences, where the backcourt players show the highest number of HIEs, followed by pivots and then wing players. This was in contrast to the results from the studies of Michalsik et al. [3, 5] who found that the wing players showed the most high-intensity locomotive activity pattern. This is probably due to the fact that the IMU measurements unlike time-motion analysis using video recording can account for all changing actions, e.g. accelerations and decelerations, also while the running speed is low. A massive physiological load is indeed imposed on players not only during the high-intensive phases of the match (intended as high-intensity running), but also every time, e.g. accelerations and decelerations are performed, even when the absolute speed is low. Thus, during organised match-play (i.e. in offence or defence), backcourt players apparently have numerous HIEs even though the absolute running speed is relatively low. Overall, the IMU studies demonstrated that elite female team handball players spend a considerable amount of energy in actions involving accelerations and decelerations, which underlines the intermittent nature of team handball also found in other studies.

There is a lack of uniformity in the few on-court analysis studies of adult elite team handball with respect to tracking systems, analysing procedures, speed zones, individual effective playing time and consideration of substitutions or rotations of the players (see [56]). In addition, sometimes the methods for providing the data are not provided. It is therefore very difficult to compare the results of the locomotion characteristics between the various studies [3, 5, 42, 47, 53–55, 57–59]. Moreover, the studies need to include a complete analysis of the technical match activities. Since team handball involves large amounts of physical contact and other technical playing actions, omission of this will lead to a systematic underestimation of the physical demands in elite team handball.

2.2.4 Physiological Aspects in Elite Team Handball

2.2.4.1 Heart Rate and Relative Workload

The optimum situation to investigate the physical demands of team handball is during official elite tournament matches. In disadvantage, some types of measurements (VO_2 sampling, blood withdrawal) cannot be performed during direct match-play. Consequently, indirect assessment of VO_2 during match-play to calculate the relative workload (RWL) expressed as % of VO_2-max based on individual HR-VO_2 relationships established in the laboratory was performed in both female and male elite players [5, 52]. This differed between male and female elite players, regarding both HR and RWL (163 vs. 171 beats min^{-1} corresponding to 71 vs. 79% of VO_2-max).

The method has previously been validated in soccer match analyses, where HR and VO_2 measured during soccer drills followed the linear HR-VO_2 relationship observed during treadmill running [60, 61]. Estimating VO_2 from heart rate (HR) measures during four-a-side team handball games was found not to be highly accurate [14].

However, by employing no resting periods, no dribbling and no physical contact with opponents, these simulated game activities differed markedly from the activity pattern typically performed during actual elite team handball match-play, which may have led to a skewed relationship between HR and VO_2. In addition, Manchado et al. [54] found mean HR during match-play to be 86% of maximum HR in female elite team handball players.

Although low-intensity activities (jogging, walking and standing still) constituted around 85% of mean effective playing time, both genders demonstrated a mean RWL of over 70% of VO_2-max during the periods of effective match-play [5, 52]. This indicates that the amount of high-intensity, strength-related technical playing actions had a marked influence on the HR response observed and hence on the RWL imposed on the players without contributing substantially to the total distance covered. Playing actions such as tackles, offensive breakthroughs, jumps and screenings may result in elevated HR for more extended periods of time (due to elevated HR in the subsequent recovery phase). Consequently, solely using the findings derived from locomotion match analyses will likely underestimate the true physical demands of elite team handball match-play. A contributing factor may arise from players running for large periods of the match with attention fixed on the ball or directly with the ball, which is known to increase VO_2 [62]. In comparison, the mentioned RWL-values are still far from the RWL in elite marathon runners that may correspond to ~90% of VO_2-max averaged over the entire race [63].

2.2.4.2 Blood Lactate Concentration

Michalsik et al. [52] found that mean post-match blood lactate concentration (BLC) was 4.8 mM for male players with large individual differences (2.8–10.8 mM), which is similar to reports on male elite soccer players [60]. The relatively high BLC values observed indicate that the rate of muscle lactate production, and hence the contribution of anaerobic energy sources, may be high during elite team handball match-play, hence indirectly supporting the notion that temporary fatigue might occur in male elite team handball. Consequently, male elite team handball appears to impose high demands on the anaerobic energy systems at least during certain periods of the match.

Lactate is produced in the muscle, and before interstitial lactate reaches a steady-state exchange with the bloodstream, a large part can be metabolised in other muscles or organs [64]. Thus, post-match BLC may be low although players during the match may have produced substantial amounts of lactate during high-intensity activities. Thus, BLC is dependent on the amount of high-intensity exercise performed in the minutes prior to blood sampling. The large interindividual variation in post-match BLC may indicate that the values obtained were influenced by the activity pattern of the players towards the end of the match. Over 30 years ago, Delamarche et al. [7] assessed the BLC in young sub-elite team handball players during practice games (30 min) and observed BLC values of 4–9 mM, which according to these authors were higher than the values derived from samples drawn only at the end of the game.

Higher BLC values might have been obtained in the study of Michalsik et al. [52], if blood sampling had been possible during the phases of active match-play (i.e. in timeouts and during substitution periods). BLC is a consequence of lactate appearance and clearance. Thus, players with low levels of blood lactate may actually work at similar, or even higher, intensities than players with high BLC due to an efficient rate of lactate clearance in the former players. Obviously, it would be more accurate to measure the lactate concentration in the muscles. However, no study has so far measured the muscle lactate production during or following team handball match-play.

2.2.4.3 Fatigue

In the studies of Michalsik et al. [2, 3, 5, 51], a reduced amount of high-intensity running, decreased HR and RWL and a reduced number of high-intensity activity changes and technical playing actions were observed during the second half, which collectively indicate that for players with an effective playing time of more than 70% of full match duration, temporary fatigue (after the most intense periods) and perhaps more permanent locomotive fatigue (towards the end of the game) may have occurred along with impaired physical performance, at least in some players.

Luteberget and Spencer [47] also found indications of temporary fatigue with measuring of external loading. However, it should also be recognised that the players' physical performance in the later phase of the match (i.e. the second half) may also be influenced by the change of match dynamics (e.g. tactical changes) and situational variables such as match location (home vs. away), quality of opposition (top, medium and bottom) and match status (winning, drawing or losing), as previously indicated in elite soccer [65, 66]. At the same time, Thorlund et al. [25] showed with acute experiments with fatigue development that maximal and rapid muscle force characteristics (rate of force development (RFD), impulse) were negatively affected following simulated team handball match-play concurrently with supressed levels of neuromuscular activity, which are likely to be associated with an impaired team handball match-play performance. Furthermore, a weight loss (0.8 kg) during an entire match equal to 0.9% of the body mass was found in male elite team handball players who were allowed to have an unlimited fluid intake during competitive matches [52]. This is below the limit suggested to cause fatigue and impair exercise performance [67].

However, notably all these studies did not examine the specific factors responsible for onset of fatigue in elite team handball. Future studies using, e.g. muscle biopsies (to measure the muscle lactate concentration and other fatigue-related substances) and blood samples taken during match-play (and not post-match) in friendly games are needed to fully examine the extent of match-induced fatigue in male elite team handball, as previously done in soccer [68].

The development of fatigue during team handball match-play could be overrated. Substitutions/player rotations in an appropriate way may be used by coaches to avoid excessive physical loading of the players by increasing the recovery time, so the players can sustain a high intensity and a high level of playing performance or at least limit a possible decrease in physical/playing performance throughout the entire match. However, to maintain a high performance level of the team during match-play, it presupposes that the performance qualities of the substitutes are high, which is not always the case, especially at elite club level. With that in mind, it may be an advantage for a team to play most of the match with the players from the starting line-up, even if they will experience some kind of fatigue during the match.

2.2.5 Physical Testing of Elite Team Handball Players

When performing an optimal physical working demands analysis, observations and measurements during actual match-play have to be carried out. Physical test results cannot directly be considered as real on-court physical demands. However, an on-court demands analysis of elite team handball players may benefit from physical test results, which can provide additional knowledge about the players' physical performance. They can be used to evaluate to what extent the physical profile has adapted to the locomotive and technical demands imposed by years of elite team handball training and match-play. Consequently, it is highly relevant to perform separate and specific physical tests (e.g. laboratory treadmill and maximal muscle strength testing, on-court jump and Yo-Yo testing and testing of repeated sprint running capacity and maximal ball throwing speed) supplemented by anthropometric measurements in elite team handball players.

Physiological profiles and physical test results varied between playing positions in both male and female players, with wing players performing better in the Yo-Yo test (intermittent running test) and showing superior jumping performance and repeated sprint running capacity compared to backcourt players and pivots [5, 52]; (see Table 2.2 for selected test results). Results from several studies [18, 20, 21, 69–74], which only included physical testing in the analysis of the

Table 2.2 Examples of the significant positional differences in selected test results for male elite team handball players [52]. Jump ability (top section), repeated sprint ability (7×30-m sprint, middle section) and throwing ability (bottom section) in male elite team handball players ($n = 26$) are shown. Results are group means ± SD (range)

	All players ($n = 26$)	Wing players ($n = 9$)	Pivots ($n = 7$)	Backcourt players ($n = 7$)	Goalkeepers ($n = 3$)
CMJ height (cm)	43.9 ± 6.0	46.4± 3.5 **	41.0 ± 3.2	42.1 ± 4.3	47.5 ± 3.4 *
CMJ height with ½ body mass (cm)	24.4 ± 2.2	24.4 ± 2.1	25.0 ± 3.4	23.8± 2.6	24.3 ± 2.2
Jump and reach (m)	0.71 ± 0.78	0.75 ± 0.71	0.70 ± 0.52	0.70 ± 0.75	0.69 ± 0.67
Standing 5-step jump (m)	13.39 ± 0.70	13.21 ± 0.86	13.43 ± 0.66	13.46 ± 0.68	13.65± 0.70
Fastest time (s)	4.09 ± 0.12 (3.87–4.28)	4.05 ± 0.12 $^{\#}$ (3.91–4.20)	4.10 ± 0.13 (4.01–4.21)	4.11 ± 0.12 (3.87–4.24)	4.15 ± 0.11 (4.06–4.28)
Mean time (s)	4.30 ± 0.13 (4.04–4.51)	4.25 ± 0.10 $^{\#\#}$ (4.09–4.49)	4.33 ± 0.13 (4.12–4.50)	4.30 ± 0.09) (4.04–4.46)	4.34 ± 0.12 (4.22–4.51)
Fatigue time (s)	0.33 ± 0.14 (0.07–0.58)	0.26 ± 0.14 $^{\#\#}$ (0.07–0.51)	0.37 ± 0.15 (0.14–0.56)	0.34 ± 0.11 (0.13–0.58)	0.39 ± 0.10 (0.31–0.51)
Jump shot (km h^{-1})	84.2±5.2	86.0±5.0	79.6±5.9 €	90.2±6.3	75.5±4.9 $^{\alpha}$
Running shot (km h^{-1})	86.1±5.5	87.5±4.4	80.8±4.5 $^{€}$	90.8±6.9	83.6±9.3
Standing set shot (km h^{-1})	86.8±6.4	88.6±5.5	78.5±4.9 $^{\#}$	92.3±7.1	87.6±8.8
Set shot with run-up (km h^{-1})	92.8±5.3 *	95.7±5.8	84.3±5.7 $^{€}$	98.6±7.3	90.4±7.6 $^{\pi}$

Difference (top section) between goalkeepers and pivots and backcourt players * $p < 0.05$ and between wing players and all other field players **$p < 0.05$; (middle section) between wing players and goalkeepers $^{\#}p < 0.05$ and between wing players and pivots and goalkeepers $^{\#\#}p < 0.05$; and (bottom section) between pivots and all other field players $^{\#}p < 0.05$, between pivots and wing players and backcourt players $^{€}p < 0.05$, between goalkeepers and backcourt players $^{\pi}p < 0.05$, between goalkeepers and wing players and backcourt players $^{\alpha}p < 0.05$ and between set shot with run-up and all other types of shots *$p < 0.05$

physical demands, have also confirmed that the physical demands in terms of the physical performing profile are related to playing positions and also to competitive level for both male and female players (see [26]).

Body anthropometry seems to have an important influence on playing performance because it is highly related to playing positions for both genders [51, 52]. Pivots are the heaviest and tallest of all playing positions, concurring with results obtained in male elite players from Croatia [75], Germany [71], Denmark [51] and Norway [70]. This likely reflects a high consistency between players' body anthropometry and the physical requirements of, e.g. pivots during match-play. Thus, large body mass (and hence muscle mass) likely has substantial importance for successful pivot playing performance due to the high frequency of in-fights and duels with opponent players. This indicates that high levels of muscle strength and RFD are essential physical performance elements in this playing position.

In contrast, wing players are lighter and smaller than all other players (including goalkeepers), which, from a physical point of view, is in accordance with the physical demands imposed on this playing position. Because of the reduced body contact both in offence and defence compared to other playing positions (see Table 2.1), high body mass and muscle strength seem of less importance for wing players. The lighter weight and smaller size of wing players enable these players to repeatedly perform rapid high-intensity movement patterns over short distances, while covering a large total distance of running per match. In general, anthropometric statistics from international team handball tournaments reveal a trend towards heavier players among the best teams, especially for male players [70].

2.2.6 Comparisons of the Physical Demands Between Male and Female Elite Team Handball Field Players

Michalsik and Aagaard [50] have published the only study so far, comparing the complete on-court physical demands between male and female adult elite team handball players, which was possible, since the aforementioned studies used the exact same analysis methods for both genders.

Marked gender differences were demonstrated for both the locomotion and technical match characteristics (see Table 2.3 for selected categories). Female players covered a longer mean total distance per match and exercised at a greater relative workload compared to male players, despite less high-intense running and fewer activity changes per match than male players. Male players received more tackles in total in offence and performed more tackles in total in defence and more high-intense technical playing actions per match compared to female players. Not surprisingly, mean body height and body mass differed between male players and female players.

2.3 Perspectives and Practical Applications

In perspective, organised attack in elite team handball typically involves relatively steady-pace playing actions, interspersed by frequent periods of standing still or walking. However, game actions comprise a high number of repetitive intense tempo changes and changes in moving direction. High-intensity running did not per se represent much of total effective playing time. Nevertheless, the ability to continuously change pace and accelerate throughout the entire match likely is of high importance for top-level playing performance. Thus, it seems relevant with an increased and differential focus in the training on improving high-intensity intermittent exercise capacity for increasing elite players' ability to repeatedly perform intense exercise and to rapidly recover after periods of high-intensity exercise. This is best done by performing especially high-intensity aerobic training on a regular basis (see Chap. 36).

High demands appear to exist for a superior acceleration and deceleration capacity, high RFD, a high ability to perform fast and hard shots, rapid side-cutting manoeuvres and a high number of strength demanding physical con-

Table 2.3 Gender differences in selected categories of the physical demands during match-play (group means ± SD) between male and female adult elite team handball players [50]

Gender differences in physical demands during match-play		
	Male players ($n = 82$)	Female players ($n = 83$)
Mean effective playing time (min)	53.85 ± 5.87	50.70 ± 5.83 *
Total distance covered (m)	3627 ± 568	4002 ± 551 *
Total distance covered, full-time players (m)	3945 ± 538	4693 ± 333 **
High-intensity running (% of total distance covered)	7.9 ± 4.9	2.5 ± 1.8 **
Standing still (% of total playing time)	36.8 ± 8.6	10.8 ± 3.8 ***
Sideways movement (% of total playing time)	7.4 ± 2.7	1.8 ± 1.3 ***
Mean speed (km h^{-1})	6.40 ± 1.01	5.31 ± 0.33 **
Activity changes (number)	1482.4 ± 312.6	663.6 ± 100.1 ***
Relative workload (% of estimated VO_2-max)	70.9 ± 6.0	79.4 ± 6.4 *
High-intense technical playing actions (number)	36.9 ± 13.1	28.3 ± 11.0 *
VO_2-max (L O_2 min^{-1})	5.18 ± 0.66	3.49 ± 0.37 ***
VO_2-max (mL O_2 min^{-1} kg^{-1})	57.0 ± 4.1	49.6 ± 4.8 ***
Fitness Index (mL O_2 min^{-1} $kg^{-0.73}$)	192.6 ± 18.2	156.4 ± 15.3 ***

Difference between male and female players *$p < 0.05$, **$p < 0.01$ and ***$p < 0.001$

frontations (i.e. tackles, screenings, claspings and blockings). Thus, an intensified focus during the competition period on anaerobic training aspects (speed training, production training and tolerance training, respectively) and on strength training on a regular basis seems highly pertinent for elite team handball players (see Chap. 36). The latter training should comprise both basic strength training and explosive-type RFD-training to make the players capable of performing the above playing actions at sustained high levels throughout the entire match. Many of the actions that are crucial for the final outcome of a match are performed at high intensity and may have a large physiological impact on the players when repeated, e.g. lead to development of neuromuscular fatigue. Excessive load in combination with insufficient recovery may affect playing performance and increase the change of injury.

Significant anthropometric developments appear to have occurred in elite team handball, where today's players were found to be markedly taller and heavier than 30 years ago. Elite team handball players need to maintain or even improve their functional capacity on the playing court such as acceleration capacity and ability to perform side-cutting manoeuvres and show high maximum jump height and movement agility, while attaining adequate intermittent endurance running capacity during match-play despite their larger and heavier bodies in order to push away in a breakthrough and to more effectively tackle opponent players in defence. Consequently, adequate specific physical training modalities should be employed in order to target these performance components to optimise the functional capacity in elite team handball including on-court jumping, sprinting and strength/RFD exercises performed with balls in game-like situations with the proper intensity, duration and recovery time. Over the last decades, the increase in body height and body mass has not been so pronounced among female elite players as among male elite players, which indicates that the strength-related aspect of the game has, relatively speaking, not nearly as much importance in female elite team handball.

It is important that improvements achieved by physical training can be transferred to the actual team handball game on the court. Therefore, the training needs to be as functional as possible. Physical training in team handball should, as far as possible, be performed on-court in game-like simulations (i.e. with ball handling involved), since such training has several advantages [64]. Firstly, the muscle coordination and the specific muscle groups used in team handball will be trained. In addition, the players' technical and tactical abilities will be developed under conditions relevant to the game. Finally, training with a ball will be more motivating for most players. an improved level of physical capacity enables players to train at increased intensity and in achieving a large total quantity of training. Position-specific physical training evidence-based recommendations for elite team handball players (both for male and female players) are presented in Table 2.4.

In a typical week for a male professional top-elite handball team with one match to play, the players will have seven to eight training sessions in 5 days (i.e. 2–3 days with two sessions), often with a day off after the match. If there is a second match during midweek, the team will train only 1–2 days with two training sessions to ensure proper recovery, while at the same time trying to peak playing performance for important matches. However, there are substantial variations depending on the training status of individual players and the experience of the coach [4]. Examples of programmes for an international top-class handball team during the regular competitive match season are presented in Table 2.5.

The amount of studies about team handball is still relatively limited. Thus, future studies should be conducted to obtain more knowledge regarding the physiology of team handball, e.g. examine the impact of different training regimens (aerobic, anaerobic and strength training) for enhancing neuromuscular fatigue resistance, physical fitness and playing performance during elite team handball match-play. Moreover, the physical demands imposed on national team players during international tournaments with multiple matches in a compressed period of time should be subject of further research, since the physical loads for elite team handball players under these conditions are likely to differ from

Table 2.4 Position-specific physical training recommendations for elite team handball players (both male and female players). RFD: Rate of force development; TDC: Total distance covered

Physical quality	Main training aim/area and rationale	Playing positions			
		Wing players	Pivots	Backcourt players	Goalkeepers
High-intensity exercise	Aim/area	High-intensity aerobic and anaerobic training	Anaerobic training	High-intensity aerobic training	High-intensity functional aerobic and anaerobic training
	Rationale	High TDC and large amount of high-intensity running	Relatively large number of fast breaks	Relatively high TDC	Short specific movements, for better recovery
Speed	Aim/area	Reaction speed and acceleration, 20–30 m	Reaction speed and acceleration, 15–30 m	Reaction speed and acceleration, <15 m	Very short specific movements
	Rationale	Longer mean sprinting distance	Longer mean sprinting distance	Shorter mean sprinting distance	Little need for normal running speed
Strength	Aim/area	Explosivity (RFD)	Hypertrophy, RFD	Hypertrophy, maximal strength, RFD	Maximal and reactive strength, RFD
	Rationale	For jumping and sprinting	For physical confrontations	For jumping, sprinting, shooting and duels/in-fights	Functional reactivity, speed and jumping
Injury Prevention	Main muscle groups	Hamstrings	Core muscles	Rotator cuff	Elbow and shoulder muscles
	Rationale	Due to the large amount of high-intensity running	Due to the large number of physical confrontations	Due to the large number of passes and shots	Due to elbow hyperextension during the many ball impacts

Table 2.5 An example of an in-season weekly programme for a professional male top-elite team handball (TH) when playing one or two regular season matches a week

Day	One match a week	Two matches a week
Sunday	Match	Match
Monday	Free or recovery training	*Morning* TH training with high-intensity running exercises, 60–90 min *Afternoon* Individual physical training - primarily strength training (RFD-training), 60 min
Tuesday	*Morning* Individual physical training - primarily strength training (RFD-training), 60 min *Afternoon* TH training with anaerobic tolerance training, 90–120 min	Tactical/technical TH training with jump training, 90 min Physical training for selected players
Wednesday	Tactical/technical TH training with jump training, 90 min Physical training for selected players	Match
Thursday	*Morning* Individual physical training - strength training (RFD-training), 60 min *Afternoon* TH training with anaerobic production training, 90–120 min	TH training - individual physical needs (much playing time/less playing time in yesterday's match), 60–90 min

Table 2.5 (continued)

Day	One match a week	Two matches a week
Sunday	Match	Match
Friday	*Morning* TH training with high-intensity running exercises, 90–120 min *Afternoon* Individual physical training - primarily strength training (RFD-training), 60 min	*Morning* TH training with anaerobic production/tolerance training, 90–120 min *Afternoon* Individual physical training - primarily strength training (RFD-training), 60 min
Saturday	Tactical/technical TH training, 90 min Physical training for selected players	Physical training for selected players, 60–90 min or free
Sunday	Match	Match

regular match season conditions that allow longer recovery time (typically one week) between successive matches.

Conclusions

Elite team handball is a physically demanding and complex game activity for both genders, where players work intensely for short, intermittent time intervals, while repeatedly performing different fast and dynamic types of locomotion and technical match activities. The game imposes moderate-to-high demands on the intermittent endurance running capacity interspersed by frequent brief periods of high-intensity running. Thus, there seem to be moderate-to-high demands on player's aerobic system as evidenced, e.g. by a mean relative workload during match-play ~70–80% of VO_2-max, while also imposing substantial demands on anaerobic energy systems as, e.g. reflected by moderate-to-high post-match blood lactate values for male players. In addition, elite team handball match-play is also characterised by a high number and a great variety of short-term, high-intense technical playing actions.

These activities include powerful upper body movements such as maximal ball throwing and tackles of opponents as well as forceful lower limb muscle actions during vertical jumping, sideways running, backwards running, forwards sprinting and rapid directional changes during fast breaks, which are performed intermittently throughout the entire match. Male and female elite team handball players need to master a complex interaction between many different movement categories and technical playing actions, including low- and high-intensity running, tackles and screenings and jump shots. Depending on their specific playing position, elite team handball players have to perform a multitude of these categories.

Furthermore, temporary locomotive and technical fatigue and impaired physical performance may occur during the time course of elite team handball match-play, at least in some players. Although seeming an obvious fact from the world of practice, studies have now shown that the on-court physical demands differ substantially between various playing positions. Moreover, physiological profiles and physical test results also differ considerably between the different playing positions. Finally, elite team handball is a highly strenuous body-contact team sport, where body anthropometry plays an important role for playing performance, with a varying influence at the different playing positions.

The observations of positional differences in locomotive and technical match activities, as well as in physiological capacity and physical profile, should be taken into account when planning physical training in elite team handball players. Consequently, modern elite team handball should comprise differential and specific physical training that is designed not only to more selectively target the various playing positions but also to the players' individual physical capacity within the same positions as well as their individual need to recover. Thus, the physical training should be organised in a more individualised manner than previously assumed at the expense of the more traditional collective way. Such individualised training may be divided into separate exercises related to the specific requirements in defence and offence, respectively. The specific findings, described in this chapter, provide valuable information about match-related activity patterns and fatigue-related changes in elite team handball players. This may come useful in future development of position-specific and individual training regimens for the planning and implementing of optimal physical training in elite team handball, as well as development of test protocols and training programmes for talent identification [76].

Considerable gender-specific variations in the physical demands exist in adult elite team handball. Physical training of female elite team handball players may potentially benefit from a greater focus on aerobic training elements. Conversely, male elite team handball players would seem to benefit from an increased training focus on anaerobic exercise elements and strength training. Additionally, the physical demands differ greatly between various playing positions both in offence and in defence, reflecting almost similar trends in both male and female elite players.

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Endocrinological Aspects in Handball

3

Alon Eliakim and Dan Nemet

3.1 Introduction

Training efficiency depends on exercise intensity, volume, duration, and frequency as well as on the athlete's ability to tolerate it. An imbalance between the training load and the individual's ability to tolerate it may result in under- or overtraining. Therefore, efforts are made to develop objective measures to quantify the fine balance between training load and the athlete's tolerability. The endocrine system, by modulation of anabolic and catabolic processes, seems to play an important role in the physiologic adaptation to exercise training [1]. Previous attempts to use the ratio of cortisol/testosterone as an indicator of the anabolic-catabolic balance in order to determine training strain had limited success [2]. In recent years, changes in circulating components of the growth hormone-insulin-like growth factor-1 (GH-IGF-I) axis, a system of growth mediators that control somatic and tissue growth [3], have been used to quantify the effects of training [4]. Interestingly, exercise is also associated with remarkable simultaneous changes in catabolic hormones and inflammatory cytokines, and the exercise-related response of these markers can be also used to gauge exercise load [5, 6]. Anabolic response dominance will eventually lead to increased muscle mass and improved fitness, while prolonged dominance of the catabolic response, especially if combined with inadequate nutrition, may ultimately lead to overtraining and injury. Therefore, it is suggested that the evaluation of changes in these seemingly antagonistic circulating mediators may assist in quantifying the effects of different types of single and prolonged exercise training and recovery modalities.

However, the vast majority of previous studies were performed in individual sports, and relatively few studies examined the levels of these anabolic/catabolic hormones in elite team sports, during different training stages throughout the competitive season, and in "a real-life" setting. This chapter summarizes the current knowledge on the effect of team sports, and in particularly handball, on these markers, and on possible ways to use these responses to assist competitive team sport athletes and coaches to better evaluate training load and optimize training.

3.2 The Anabolic-Catabolic Systemic-Local Training Model

Previous studies have suggested the hypothesis that a sudden imposition of a training program which is associated with substantial increase

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in energy expenditure leads initially to an increase in pro-inflammatory cytokines and, as a consequence, to decreases in IGF-I levels. Further, if the training adaptation is successful, the pro-inflammatory cytokine levels fall, and with that decrease, the suppression of IGF-I diminishes, and an anabolic "rebound" in components of the GH-IGF-I axis ensues, leading to IGF-I level that exceeds the pre-training level [7]. Exactly how and when this switch occurs and whether the initial catabolic-type stage is necessary for the ultimate anabolic training adaptation ("training effect") remains unknown.

Interestingly, previous studies have also shown that despite the early decrease in circulating IGF-I level, training may induce increases in muscle mass. This suggested that the effect of exercise on local muscle tissue growth factors may differ from its systemic effects. Moreover, the local muscle IGF-I response to increased muscular effort occurred and was even enhanced, also when GH was inhibited [8, 9] emphasizing the GH independence of the "local" IGF-I anabolic adaptations to exercise. What is the advantage of simultaneous central catabolism and local anabolism early in the adaptation to increased physical activity? This adaptive mechanism may reduce global anabolic function, thereby conserving energy sources, yet still allow for local tissue growth in response to environmental stresses like exercise training (Fig. 3.1). Consistent with this speculation is the phenomenon that occurs following intense exercise training in nutritionally, self-deprived, young elite athletes (e.g., female gymnasts [10]), where muscle adaptation occurs despite attenuated somatic growth and reduced circulating IGF-I.

Fact Box
The endocrine system, by modulation of anabolic and catabolic processes, seems to play an important role in the physiological adaptation to exercise.

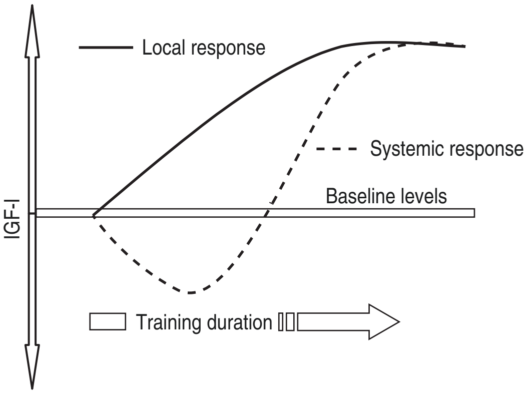

Fig. 3.1 Systemic and local adaptations of IGF-I to exercise training. Systemic IGF-I response is composed of an initial catabolic-type response with a decrease in IGF-I levels, which with proper training is followed by a rebound increase in IGF-I levels. On the other hand, muscle IGF-I usually increases from the early stages of training

3.3 Team Sports

3.3.1 Effect of Single Exercise

The effect of treadmill exercise testing to maximal effort on stress hormones was determined in elite athletes from team (i.e., handball and soccer) and individual (i.e., kayak and triathlon) sports [11]. Interestingly, the increase in adrenaline and in particularly noradrenaline was significantly greater among team-sports players even when the change was normalized to maximal oxygen consumption. The authors suggested that the greater catecholamine increase indicates an adaptation needed for ball games players due to the characteristic game intermittent activity pattern that uses both aerobic and anaerobic energy sources.

Interval training is one of the most frequent training methods used in anaerobic and aerobic-type sports [12]. The intensity of such training depends on the running distance (short versus long sprints), running speed (percent of maximal speed), the number of repetitions, and the length of the rest interval between runs. In addition, coaches and athletes change very often the interval training style and use constant running distances (e.g., 4 × 250 m), increasing distance sessions (e.g., 100 m–200 m–300 m–400 m), decreasing distance sessions (e.g., 400 m–300 m–200 m–100 m), or a combination of increasing-decreasing distance interval sessions (e.g., 100 m–200 m–300 m–200 m–100 m). While these style differences may seem negligible, they may involve different physiological demands, since in the increasing distance protocol, metabolic demands (e.g., lactate levels) increase gradually and are highest toward the end of practice, while in the decreasing distance protocol metabolic demands are higher from the beginning and throughout the session [13].

Recently, we demonstrated in elite young national team level male handball players a significant increase in GH and testosterone levels following a typical constant distance (4 × 250 m) interval training [13]. Consistent with previous findings in aerobic exercise, changes in the GH-IGF-I axis following the brief sprint interval practice suggested exercise-related anabolic adaptations. In addition, the interval training session was also associated with an increase in the pro-inflammatory marker interleukin-6 (IL-6) indicating its possible role in the postexercise muscle damage healing process and suggesting that anabolic, catabolic, and inflammatory markers may be used to assess interval training load as well. In addition, we evaluated the effect of increasing (100–200–300–400 m) and decreasing distance (400–300–200–100 m) sprint interval training protocols, on the balance between anabolic, catabolic, and inflammatory mediators [13]. Both sprint interval training types led to a significant increase in lactate and GH and IGF-I. Interestingly, lactate levels and GH area under the curve were significantly greater in the decreasing distance session. In contrast, rate of perceived exertion (RPE) was higher in the increasing distance session. Thus, despite similar running distance, running speed, and total resting period in the two interval training sessions, the decreasing distance interval was associated with a greater metabolic (lactate) and anabolic (GH) response (Fig. 3.2). Interestingly, these greater metabolic and anabolic responses were not accompanied by an increase in RPE suggesting that physiological and psychological responses to interval training do not necessarily correlate. When the athletes were asked to explain why the increasing distance training protocol was perceived as more intense, they replied that the fact that the longest and hardest run (400 m) was only at the end of the session was very difficult to tolerate. Coaches and athletes should be aware of these differences and the need for specific recovery adaptations after different types of interval training sessions. Differences in physiological and psychological responses to competitive sport training, and their influence on the training course and recovery process, should also be addressed.

We previously demonstrated an increase in GH, testosterone, and IL-6 levels following a typical volleyball practice in adolescent national team level male and female players [14]. The results suggested the possible use of these markers in the assessment of “real-life” team-sports practices as well. Interestingly, baseline and postexercise testosterone levels were significantly higher in the males compared with females. However, training was associated with an increase in testosterone levels in both genders, and the response to training was not significantly different between genders. The testosterone increase may indicate an exercise-associated anabolic adaptation. Our results suggest, therefore, that an increase in testosterone levels may play an important role in the anabolic response to exercise in female players as well. Very few studies examined the effect of team-sports training of testosterone levels in female athletes. In contrast to our findings, there were no significant changes in circulating testosterone and salivary testosterone levels in elite female players following an intense water polo practice and handball match, respectively [15, 16]. In contrast to male athletes, in which the source of the exercise-induced testosterone production is testicular, in female athletes, testosterone is produced by the adrenal gland. Accordingly, postexercise increases in testosterone levels in female athletes were usually accompanied by a parallel increase in cortisol and other adrenal androgens [17].

In addition, we recently studied [18] the influence of physical contact on neuromuscular fatigue and inflammatory responses during handball small-sided games (SSG) and demonstrated that

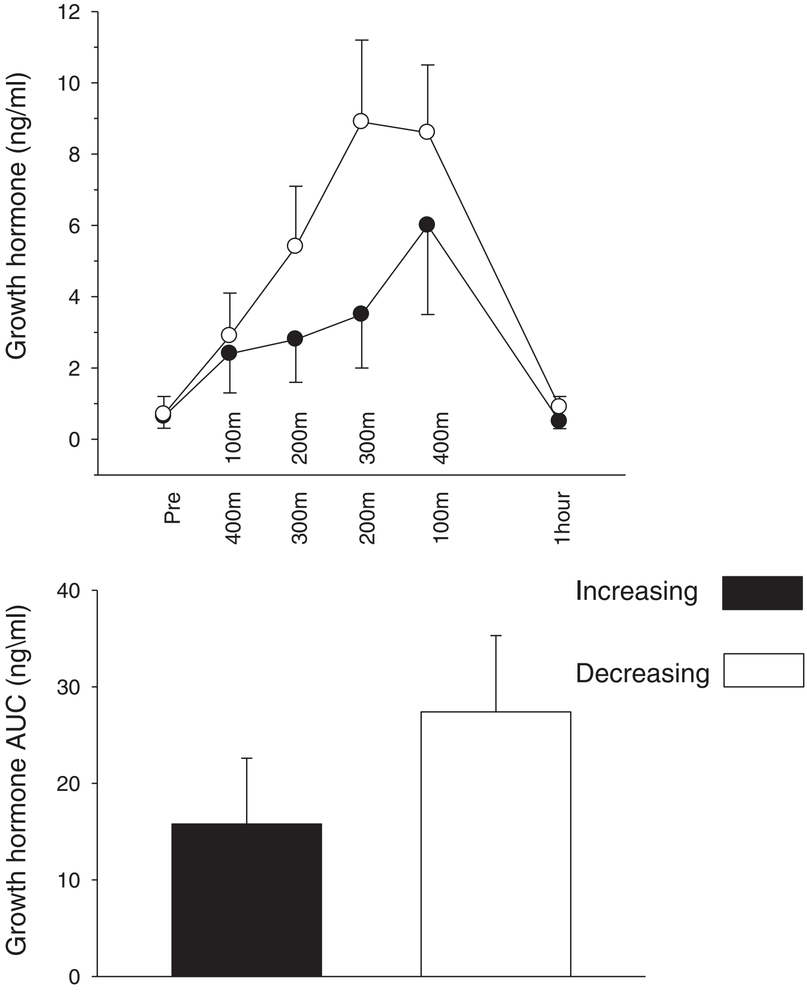

Fig. 3.2 The effect of decreasing and increasing distance sprint interval exercise on GH and GH area under the curve. The decreasing distance interval was associated with a greater anabolic [GH (upper) and GH AUC (lower)] response

the presence of physical contact in 3-a-side SSG resulted in greater upper and lower body neuromuscular impairment compared to the same training regimen without physical contact. Moreover, an increase in the inflammatory marker IL-6 was found only following the physical contact practice, and a very strong relationship was found between the IL-6 response and the number of physical contacts during the training regimen. It is possible that physical contacts were associated with greater muscular macro- and microtrauma and inflammation leading to increases of IL-6 levels. This is consistent with the previous finding that contact SSG in handball resulted in greater increases in serum CK levels compared with no physical contact SSG [19], indicating greater muscle damage following contact SSG. Moreover, a comparison of IL-6 changes following typical individual and team, contact and noncontact sports, and field practice sessions showed that the greatest increase in IL-6 was found following wrestling practice [20].

The development of methods to enhance the recovery of elite athletes from intense training and/or competition has been a major target of athletes and their accompanying staff for many years. Cryotherapy is widely used to treat sports-associated traumatic injuries and as a recovery modality following training and competition that may cause some level of traumatic muscle injury [21, 22]. However, evidence regarding the effectiveness and appropriate guidelines for the use of cryotherapy are limited. We evaluated the effect of cold ice-pack application following a brief sprint interval training on the balance between anabolic, catabolic, and circulating pro- and anti-inflammatory cytokines in 12 male, elite junior handball players [23]. The interval practice (4 × 250 m) was associated with a significant increase in GH and IL-6 levels. Local cold-pack application was associated with significant decreases in the anabolic factors IGF-I and IGF-binding protein-3 during the recovery from exercise, supporting some clinical evidence of possible negative effects of cryotherapy on athletic performance. These results, along with no clear effect on muscle damage or delayed onset muscle soreness (DOMS), may suggest that the use of cold packs should probably be reserved for traumatic injuries or used in combination with active recovery and not with complete rest.

Fact Box
The anabolic adaptation to exercise may be influenced by recovery modalities (e.g., cryotherapy).

However, this is an example of how exercise-induced changes in the GH-IGF-I axis and other catabolic and inflammatory markers may be used to solve the puzzle of optimizing competitive training. Further studies are needed to explore the beneficial use of anabolic, catabolic, and inflammatory markers measurement in many other aspects of the recovery from exercise.

Fact Box
The magnitude of the hormonal response to exercise is influenced by the intensity and type of sports, the participants' fitness level, and the timing along the competitive season.

3.3.2 Effect of Prolonged Training

Very few studies examined the effect of prolonged training on hormonal status in handball players. The effect of additional heavy resistant training during 6 weeks of handball training among male adolescent players was associated with greater gains of maximal strength and throwing velocities but with reduced gains in vertical jump and endurance performance [24]. The authors also reported a decrease in testosterone/cortisol ratio in the handball + resistance training group compared to the handball training only and suggested that this decrease may indicate overtraining. Consistent with that, the effect of training on salivary cortisol, the adrenal androgen DHEAS, and DHEAS/cortisol ratio was determined in female handball and volleyball players [25]. Results showed an increase in resting DHEAS and androstenedione levels and DHEAS/cortisol ratio. However, there was a negative correlation between the amount of training and the DHEAS/cortisol ratio throughout the training period (16 weeks) suggesting that this ratio can be used as an index of training load.

Measurements of hormones and in particularly IGF-I levels can also assist athletes and coaches in the training preparation for selected competitions. The effect of 4 weeks of training on fitness, self-assessment physical conditioning scores, and circulating IGF-I was determined in elite professional handball players [26] during their preparation for the junior world championships. Training consisted of 2 weeks of intense training followed by 2 weeks of relative tapering. Circulating IGF-I and physical conditioning scores decreased initially and returned to baseline levels at the end of training. There was a significant positive correlation between the changes in circulating IGF-I and self-assessment physical conditioning scores suggesting that the player's self-assessment might serve as a reliable tool when laboratory assistance is unavailable (Fig. 3.3). Moreover, in a study by Sa et al. [27], handball players demonstrating more discomfort/pain using the fibromyalgia trigger point were found to have higher in vitro mononuclear cytokine production and more reported nontraumatic muscular injuries throughout the season.

Consistent with these findings, a follow-up of IGF-I levels during the training season in elite adolescent wrestlers showed also a decrease in IGF-I level during periods of heavy training and return to baseline during tapering down and prior to the competition season [7]. Interestingly, changes in the pro-inflammatory mediators IL-6

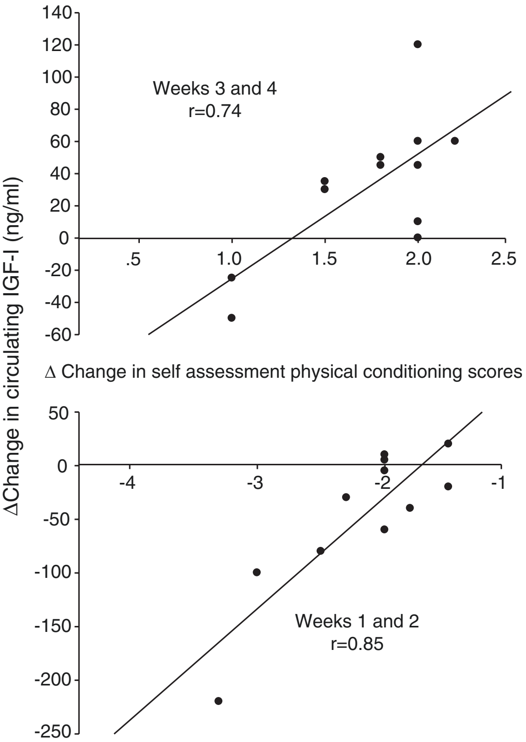

Fig. 3.3 Relationship between changes in self-assessment physical conditioning scores and change in circulating IGF-I in handball players. Relations are reported for weeks 1 and 2 (intense training) and weeks 3 and 4 (tapering). There were significant correlations between self-assessment scores and change in circulating IGF-I

correlated negatively with changes in IGF-I, being high when IGF-I level were low, and normalized when IGF-I levels normalized, emphasizing their potential contributing role for the training-associated change in IGF-I.

Tapering down the training intensity prior to the competition is a well-known training methodology to help the athlete to achieve his best performance [28]. This strategy is indeed associated with a parallel increase in circulating IGF-I levels and a decrease in inflammatory cytokines. Therefore, these measures may assist coaches and athletes in their training preparations.

Fact Box
The usage of the hormonal response to exercise as a practical tool to monitor training load and response should be individualized.

Interestingly, in type of sports that do not plan their training for a specific targeted date, like many of the team sports that train in the same relative intensity throughout a regular season (e.g., handball, soccer etc.), changes in IGF-I level and its major binding protein IGFBP-3 were not found [29].

In optimal conditions, during the tapering of training intensity, IGF-I level will increase above baseline levels and will be associated with improved performance; however, this does not occur always. Since IGF-I can be reduced by nutritional imbalance and weight loss, it is possible that a deliberate decrease in body weight in athletes who participate in weight category sports (e.g., judo, wrestling), or even in team-sport players prior to major tournaments, may prevent further increase in this anabolic hormone and will be associated "only" with a significant return to baseline values [7, 30]. This emphasizes the importance of proper nutritional consoling along the training season. Previous studies have demonstrated in athletes, a training-associated negative correlation between circulating IGF-I and ghrelin, a hormone that is secreted by the stomach and pancreas and known to stimulate hunger [31]. Moreover, decreases of ghrelin and leptin, both known to mediate energy balance, were found following 3-month preseason preparatory training in young female handball and basketball players [32]. All together this suggests that hormonal relationships play a mediating role in training-induced associated energy balance, appetite, body composition, and muscle performance changes.

Interestingly, despite decreases in *circulating* IGF-I during period of intense training, fitness may still improve, as muscle mass does [33–36]. This suggests that while changes in *circulating* IGF-I are good markers of the general condition and energy balance of the athlete, they are not necessarily good indicators of the athlete's performance. Probably, it is the local muscle levels of these hormones and their autocrine or paracrine secretion, that is more indicative of skeletal muscle performance [9, 37]. Tapering of the training intensity, however, was found to be associated with both increased IGF-I level and with further improvement of exercise performance of the athletes [28, 38].

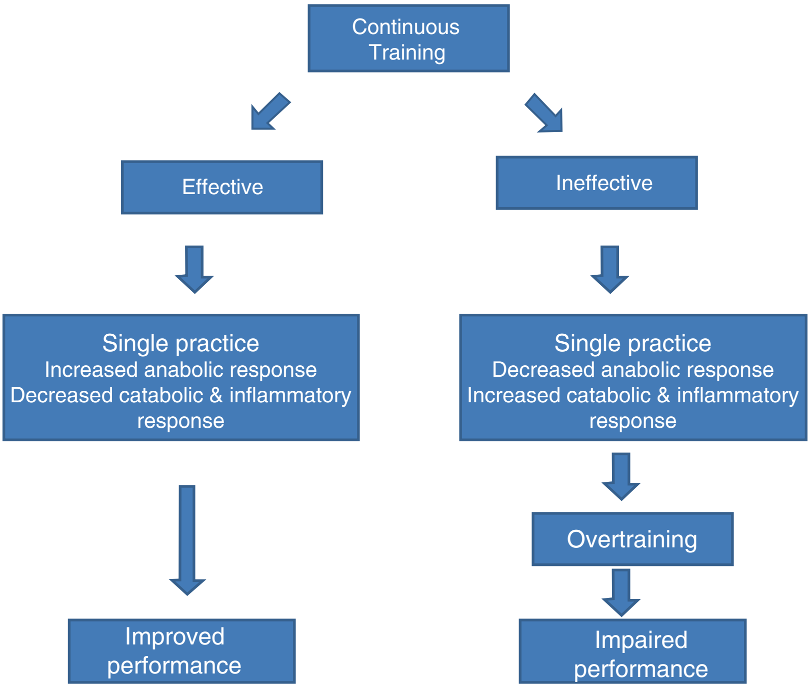

Fig. 3.4 The exercise-training-IGF-I model. During the initial phases of the training season, effective training adaptation will lead to a more anabolic and less catabolic/inflammatory response to each single practice and to better performance. Ineffective training will lead to a prominent catabolic response that may lead to overtraining and impaired performance

It is still unknown what should be the permitted decrease of IGF-I levels during periods of heavy training or what should be the optimal increase of this substance during periods of tapering down and reduced training intensity. However, we believe that an inability to increase circulating IGF-I levels before the target competition should be an alarming sign for both the athlete and his/her coach that the athlete's general condition is not optimal. Collection of baseline and training-related hormonal changes, with a comparison to the hormonal response in previous seasons, and the knowledge and experience of the past success may prove to be of a very significant relevance as well.

One of the most important findings is the effect of training on the endocrine response to a single practice. The hormonal response to a typical 60 min volleyball practice was assessed before and after 7 weeks of training during the initial phase of the season in elite national team level male and female players. In male players [39], training resulted in significantly greater GH increase along with significantly reduced IL-6 response to the same relative intensity volleyball practice. In female players [40], training resulted in significantly lower cortisol and IL-6 increase to the same relative intensity volleyball practice. The results suggest that along with the training-associated improvement of power, anaerobic, and aerobic characteristics, part of the adaptation to training is that a single practice becomes more anabolic and less catabolic/inflammatory as training progresses during the initial phases of the training season (Fig. 3.4). Hormonal measurements therefore may assist athletes and their coaching stuff in assessing the training program adaptation throughout different stages of the competitive season.

Fact Box
The balance between anabolic and catabolic responses to exercise may be used to gauge exercise load in individual as well as in team sports.

3.3.3 Effect of Handball Match

Similar to the effect of training on the endocrine response to a single practice, 16 weeks of handball training were associated with an increase in cortisol levels only during the first week game, suggesting that handball matches become less stressful as the training continues [25].

Inflammatory responses and muscle damage indices following a match were compared between four popular elite level team sports (i.e., soccer, basketball, handball, and volleyball). Soccer produced the greatest increases in cortisol, the inflammatory marker IL-6, as well as muscle damage indices, while volleyball showed the smallest increases compared to the other sports [41]. This result suggests that among popular ball games at elite level, handball match leads to a relatively moderate stressful and inflammatory response. Along with that, levels of salivary cortisol before and after a competitive match were higher among elite female handball compared to volleyball players [42]. The state of anxiety was also significantly higher among the handball players characterized by type A behavior, whereas type B behavior defined the volleyball players. It is possible that the different hormonal responses in different ball games are related not only to different metabolic demands but also to individual player's personality characteristics, anxiety state, and ability to tolerate the match and its outcome (win or lose).

Fact Box
Following training, along with the training-associated improvement of power, anaerobic, and aerobic characteristics, a single practice becomes more anabolic and less catabolic and inflammatory, and a single match becomes less stressful.

3.3.4 Effect on Performance

Previous studies in Italian handball national team players during their preparation to the European handball championships showed that improved jumping performance (maximal single jump height and average mechanical power for 15 s consecutive jumps) correlated with increase in testosterone and cortisol levels and upregulation of the glucocorticoid receptor capacity [43]. The authors concluded that adequate levels of testosterone are prerequisite for improvement of explosive performance in elite handball players. Similarly, a significant correlation was found between resting testosterone levels and vertical jump performance among elite sprinters, handball, volleyball, and soccer male and female players [44]. The results also indicated that testosterone levels can serve as a marker of jumping performance among female players as well, despite the significantly lower levels of testosterone compared with males (less than 10% of the men).

Finally, previous studies have found that a higher social rank was associated with higher levels of IGF-I in both men and women, independent of wide range of known confounders such as age, ethnicity, body weight, nutrition, and exercise [45]. Recently, Bogin et al. [46] studied high-level male and female competitive athletes from different university team sports [men (lacrosse, handball, rugby, and volleyball) and women (football, rugby, netball, and volleyball)] and assumed that what determines the social rank in this unique social network is the level of success in sports (and not the economic status). Therefore the athletes were divided to winners and losers. The main finding of the study was that both pre- and post-competition IGF-I levels were about 11% higher among winners. There was no difference in the competition-related changes in IGF-I levels between the groups, suggesting that it is the baseline levels of IGF-I and not the change in IGF-I levels during the competition that may contribute to winning. This is the first study that relates IGF-I levels with winning.

Fact Box
A better anabolic profile (e.g., IGF-I) may be associated with winning in team sports.

It seems that IGF-I levels integrate the multiple genetic, nutritional, social, and emotional

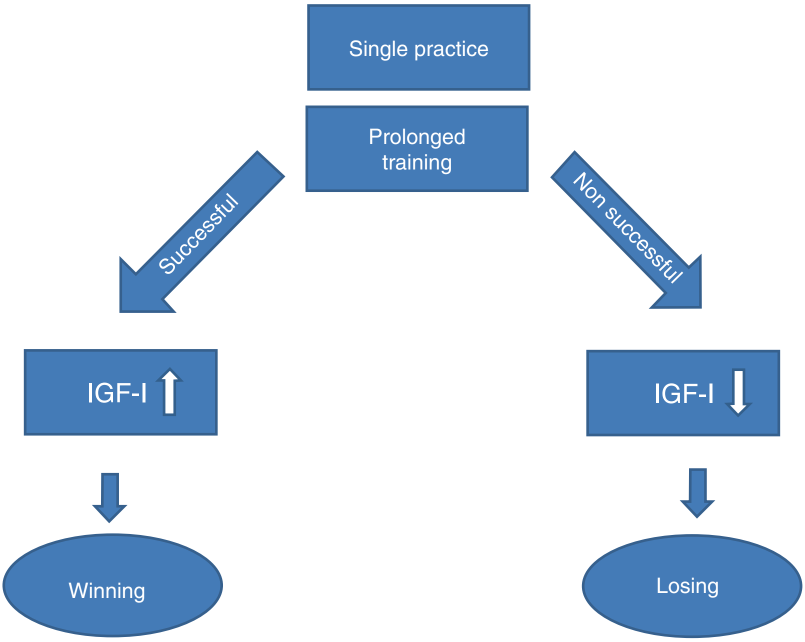

Fig. 3.5 The exercise-training-IGF-I cycle. With proper training, both single practice and prolonged training increase IGF-I levels, which in turn increase the chances of an athlete to win

influences to a coherent signal that regulates growth and possibly athletic performance. This suggests a novel cycle: both single practice and prolonged training increase IGF-I levels, which in turn increase the chances of an athlete to win (Fig. 3.5). However, future larger studies that analyze other types of team sports and individual sports and that better control for nutritional, training, and doping status are needed to confirm this very interesting finding.

3.4 Summary

Efforts to find objective parameters to quantify the balance between training load and the athlete's tolerance have been so far only partially successful. The complexity of the hormonal responses to different exercise types, in a variety of sports disciplines and during different phases of the competitive season, has become increasingly apparent in recent years. This chapter suggests that as demonstrated in individual sports, the evaluation of the hormonal response to exercise may be used as a helpful objective tool to assess the physical strain of training in team sports such as handball as well.

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4 The Shoulder Profile in Team Handball

Georg Fieseler, Kevin G. Laudner,
Souhail Hermassi, and Rene Schwesig

4.1 Traumatic Shoulder Injuries

According to data from the responsible insurance company for team handball professionals in the first and second German league, 25.8% of handball players reported sustaining injuries during the 2015/2016 season [1, 2].

With regard to traumatic injuries, the shoulder is not the most commonly injured joint among handball players. According to the insurance company data from the top 2 leagues in Germany in the season 2015 and 2016, it was the fourth most commonly injured joint (9.3%) behind the hand (9.9%), the knee (13.2%), and the ankle (13.8%) [2]. However, the shoulder required the third longest interval of convalescence after trauma, following knee and ankle injuries [2]. Sequential analysis of this data showed that shoulder injuries were comprised of sprains (38.9%), contusions (28.1%), dislocations (6.5%) (mostly acromioclavicular joint dislocations), tendon tears (4.3%), muscle damage (14.6%), and others (7.6%) [2]. According to this data, shoulder injuries in handball players predominantly stem from direct contact (68.3%), defined as an injury resulting directly from contact with another player, and indirect contact (29.3%), defined as an injury resulting from contact, e.g., with the floor following contact with the opponent but rarely from a noncontact mechanism (2.4%) [2]. Therefore, traumatic shoulder injuries are quite common among professional players [3, 4].

4.2 Microtrauma to the Shoulder

In regard to injuries caused by overuse, research has shown that among handball players, the shoulder is one of the most commonly injured joints, with up to 30% of these pathologies occurring acutely and 45% through persistent symptoms [3, 5–7]. Direct consequences of ongoing stress causing structural damages were found in ultrasound or MRI techniques [8–10].

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Key Box I

Macro-traumatic injuries of the shoulder in handball athletes occur quite often and regularly follow an algorithm for treatment in most trauma clinics. Micro-injuries like overload, acute, or chronic overuse are described as well, but little is known about the causation and a prevention concept for onset. The detection of workload and assessment of impairments as predictors can be used for preventive therapeutic strategies and may minimize the risk of shoulder injury.

4.3 Athlete's Performance

During a complete season, a professional team handball athlete performs up to 48,000 throwing actions with a maximum of 130 km/h and an angular velocity of 7000 °/s, which means 20 turns/min and 150–170 km/h of the throwing arm [6, 11–16]. Research has reported that the forces on the anatomic structures of a throwing shoulder during the throwing motion can be up to 1.5 times the individual's body weight [17–19].

4.4 Methodological Aspects for Athlete's Shoulder Care

Wilk et al. [20] first proposed a reproducible and reliable concept and method to examine overhead athlete's total shoulder range of motion (t-ROM) [20]. The t-ROM is calculated as the sum of maximum internal rotation ROM (IR-ROM) and external rotation ROM (ER-ROM) with the shoulder in 90° of abduction and the elbow in 90° flexion [20] (Fig. 4.1).

Many overhead athletes present with a glenohumeral internal rotation deficit (GIRD), which is defined as the difference between an IR-ROM in the throwing (TS) and the non-throwing shoulder (NTS) [20]. This deficit is typically described as a negative value and includes a concomitant increase in external rotation, known as external rotation gain (ERG) [20]. Similarly, this gain is defined as the difference in ER-ROM between limbs and is typically described in positive value [20].

Numerous studies have shown that reliable assessment of active and passive ROM as well as isometric strength can be determined using a standardized testing protocol with a standard goniometer and handheld dynamometer [21–24].

In practical application the athlete is examined for pre-existing shoulder problems and injuries, as well as a specific clinical examination [23, 25,

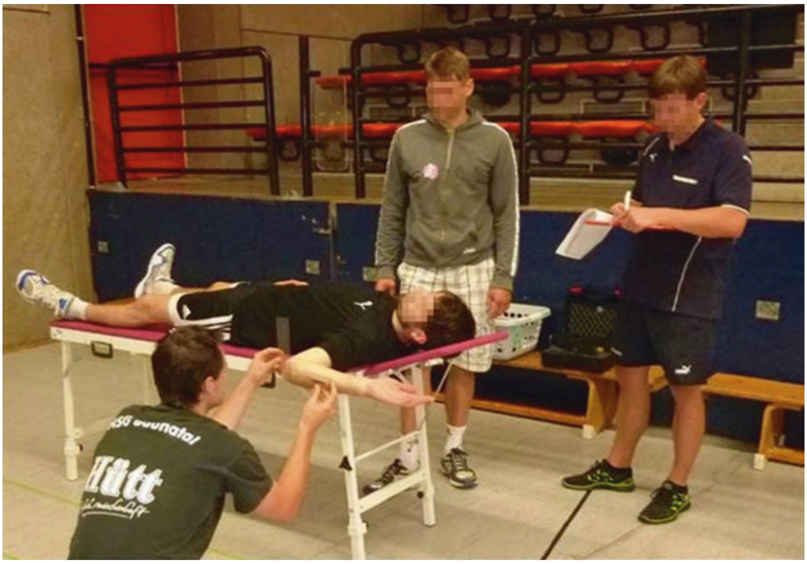

Fig. 4.1 Examination for range of motion (ROM)

26]. Differentiation for the throwing or non-throwing shoulder should be based upon the actual real use in sports, not according to the “right” or “left” shoulder joint.

The parameters of IR-ROM and ER-ROM are determined actively with the athlete positioned supine on a standard examination table, the scapula manually stabilized, and the test arm in a position of 90° of shoulder abduction, 90° of elbow flexion, and the forearm in a neutral rotation (supination and pronation 0°) [23, 25, 26]. The elbow joint and shoulder are traditionally stabilized by a second examiner, while the first examiner uses a goniometer for measurement [23, 25, 26]. Each measurement is performed by two clinicians but always the same examiners to ensure reproducibility and reliability. The t-ROM, GIRD, and ERG should be calculated.

Evaluation of isometric shoulder strength should also be conducted in a supine position with the athlete’s scapula and elbow stabilized while using a handheld dynamometer [23, 25, 26]. Mean strength values should be calculated from three measurements bilaterally. These examinations should be performed prior to training sessions or warm-ups.

4.5 Pathophysiological Aspects

Kinematic studies for investigation of a throwing action were first completed for the purpose of generally visualizing kinetic forces and loads. These types of studies have been extensively used in baseball, which reflects the extreme loads placed on the shoulder [27]. Unfortunately, these types of studies have not been used much for team handball. Handball requires players to throw in a variety of positions, so these loads can change. More specifically, handball athletes incorporate various throwing techniques such as the jump throw, standing throw, standing throw with run-up, hip throw, and pivot throw. Therefore, which phase of throwing action causes the strongest workload partly remains unclear [16, 28, 29], but studies underscored data that the highest stress on the shoulder can occur during the cocking and deceleration phases [16, 28, 29] (Fig. 4.2).

Fig. 4.2 Center player in jump-shot motion

The consequences of these intense loads in maximum rotation and angular velocity are changes in rotational capacities as well as functional and structural adaptations in the shoulder. Most of the investigations of rotational capabilities and influences on this issue to date have been performed with baseball players [30–38].

In accordance to these investigations, only a few studies have been published in handball players, one in female professionals [4], a longitudinal study without recurrent clinical examinations of the affected joints [39], and one with multiple examinations over an entire competitive season [23, 25, 26].

The accumulation of forces among overhead athletes can cause reduced internal rotation, increased external rotation, and overall restricted total range of motion (ROM) in the shoulder compared to the non-throwing shoulder [40, 41]. These changes can be caused by osseous adaptations via retroverted positions of the humeral head in baseball and team handball athletes [6, 14, 42, 43] (Fig. 4.3).

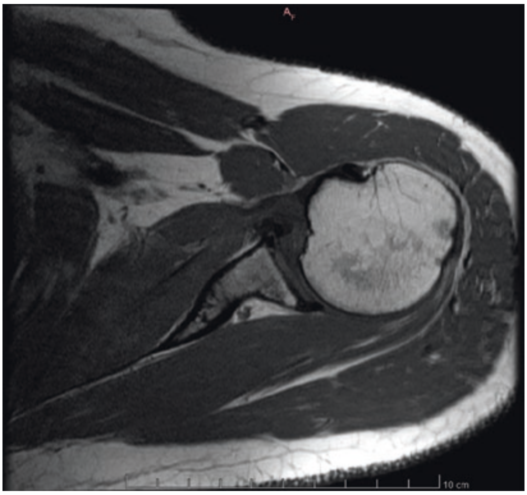

Fig. 4.3 Right Humerus head of former team handball goal-keeper (42 years old) after 25 years of active sport

Other studies suggest an attenuation and weakness of the anteroinferior capsule and ligamentous tissues in the throwing shoulder due to the repetitive workload. Situations like "posteroinferior glenohumeral impingement (i.e., internal impingement) syndromes," as described by Jobe [44] and Walch [45], might occur consequently as the shoulder reaches maximum external rotation. Alternatively Burkhart introduced a pathophysiological concept with contractures of the posteroinferior capsule and posterior part of the inferior glenohumeral ligament as well as a shift of the center of rotation for the humeral head to a more posterosuperior position resulting in an anterior "pseudolaxity" [46, 47].

Kibler [48] summarized the data in his review and postulated a multifactorial etiology for changes in rotation that occur in a sequential manner with considerable overlap among several factors. In adolescent years response to torsional loads occurs in the bone as the earliest change. As the years of sports activity increases along with the increased exertion of throwing, higher eccentric and tensile loads are applied to the posterior muscle groups which can result in sarcomere changes due to acute demands and stiffness as well as increased muscle tension after chronic exposure [49]. These mechanisms are more frequently related to the 16- to 30-year-old age group. With chronic and ongoing stress in older throwers (age 25–40 years), the capsular causation is seen more predominantly [48].

4.6 Influence on Shoulder's ROM and Strength during an Entire Season

Fieseler et al. underscored the presence of different answers to the throwing demand even during a complete competitive season [23, 25, 26]. Current observations have reported changes in kinematics or strength in the throwing shoulder of baseball players [20, 30, 33], but few studies described the influences in team handball for either female or male athletes [4, 28, 29, 50–55].

Because of the repetitive nature and accumulation of forces on the capsuloligamentous and muscular structures, the throwing shoulder has to adapt to maintain sports-specific performance in a dynamic manner. Owing to the ongoing load during the competitive season, the demand for external rotation ROM, and subsequent force development, which is essential for a throwing action, the center of the humeral head may shift to a more posterosuperior position on the glenoid's articular surface to provide maximal external rotation ROM [23, 46, 47]. Under this new position, the humeral head is able to maintain better ER-ROM and throwing performance, which correlates with the data shown in our studies [23, 25].

During the second half of a competitive season (weeks 22–40), handball players were shown to have a significant reduction in t-ROM as well as an improvement of the previously increased GIRD and ERG in the throwing shoulder. These changes may be somewhat of a consolidation following this volume of influences [25].

Key Box II

It could be demonstrated that a specific workload accumulated during the weeks of an entire handball season leads to functional, pathophysiological, and structural consequences in athlete's shoulder joints and resulted in changes to rotational capacity and isometric strength [22, 23, 25, 26].

4.7 Risk Factors and Predictors

Regardless of which mechanism previously mentioned explains the soft tissue or osseous adaptation in the loaded thrower's shoulder, there is evidence (formally shown in baseball and currently for handball) for the increased risk of developing posterosuperior glenohumeral and subacromial impingement syndromes, superior labral anterior-posterior (SLAP) lesions, anterior instability, and rotator cuff pathologies because of overuse causing microtraumatic lesions [28, 29, 38, 52, 56–58].

Clinicians may consider players who present with a loss of IR-ROM that is equal to the increase in ER-ROM in the throwing arm, resulting in t-ROM equal to that of the non-throwing arm, as a potential physiologic adaptation for enhanced performance and decreased risk of injury [6, 48, 52–54, 59]. This has been confirmed for asymptomatic athletes in various studies, mainly in baseball [10, 20, 37, 60, 61], as well as tennis [62, 63] and handball [6, 64].

Although adaptations in shoulder ROM are common among handball players, several risk factors have been identified as pathological. Various studies stress the importance of the bilateral evaluation of the t-ROM in overhead athletes [20, 32, 33, 38], because a difference between the t-ROM of the throwing to the non-throwing shoulder may be a predictive factor for injuries or structural damages.

Wilk et al. [20] examined the t-ROM in 170 baseball players and found athletes who have a bilateral t-ROM deficit of greater than >5° are 2.5 times more likely to have an injury in the throwing arm [20]. Ruotolo [37] reported a loss of t-ROM in the throwing shoulder of youth baseball players and calculated an increased risk for shoulder problems and pain [37]. Similarly, a cross-sectional investigation from Myklebust et al. [4] described a high prevalence of shoulder pain or injuries for female team handball athletes [4]. Clarsen et al. [51] found in their cross-sectional cohort study a significant association between shoulder injuries and the t-ROM in the throwing shoulder among male team handball players [odds ratio (OR) = 0.77 per 5° change] [51]. In one of our investigations, we determined a 5° reduction of t-ROM in the throwing shoulder at the end of the surveillance, compared to the baseline examinations [25]. Therefore, a statistically higher risk and susceptibility for an injury could be calculated, although we fortunately did not experience any injury during our 40-week observation [25].

External rotation deficit (ERD) was introduced by Wilk et al. [20, 38] and is defined as the difference between the ER-ROM of the throwing and the non-throwing shoulder of less than 5°. When comparing an athlete's ER-ROM from side to side, a difference of more than 5° indicates that the player's ER-ROM gain on his throwing side is significant enough to contribute to the demands of throwing, especially during the late cocking phase [53]. Unpublished data by Wilk et al. [58] demonstrated that an ERD can result in a 2.3 times higher risk of sustaining a shoulder injury [53, 58]. Therefore, the authors concluded that an insufficient ER-ROM on the dominant shoulder may put the athlete at a higher risk for injury [53, 58]. These results were observed in professional American baseball pitchers [53, 58]. Unfortunately, data in handball players is still unknown in this area.

Ratio values created by ER-ROM to IR-ROM volumes were discussed by studies from Clarsen et al. [51] and Andersen et al. [65] being risk factors for shoulder injuries. Although data in these studies showed no statistical significance, the trend toward lower ER-ROM:IR-ROM ratios was considered being a potential risk factor for shoulder trauma.

Glenohumeral internal rotation deficit (GIRD) as described by Burkhart et al. [46, 47] is known as a primary risk factor for shoulder injuries and soft tissue damages [36, 61, 66, 67]. Since described first in 1990 [39], GIRD is known to increase (decreased IR of the throwing shoulder) along with the years of throwing exposure in several sports [62, 68], over a competitive season [33, 69], and acutely after a throwing exposure [70, 71]. Kibler postulated in his review article [48] that IR-ROM, t-ROM, and GIRD are dose or exposure dependent, because baseball starters and relievers have shown different amounts of change in IR-ROM and GIRD over a competitive season [33]. A pathologic condition has been recognized in an extension of GIRD without simultaneous compensation of the ERG, which is described as predisposition for development of symptoms such as pain and structural changes [5, 36, 37, 61]. Many authors in their studies have concluded a mean range of GIRD from 10–15° in asymptomatic overhead athletes [31, 36, 60, 71, 72] and a mean range 19–25° in symptomatic overhead players [36, 66]. Lubiatowski et al. [52] reported that handball players with greater than 20° of GIRD had an increased risk of shoulder pain and those with greater than 25° of GIRD or greater than 20° of lost t-Rom had a higher risk of internal impingement [52]. For team handball professionals, Almeida reported a significant extension of GIRD and ERG as well as an increase in ER-ROM and a decrease in IR-ROM in the throwing shoulder of athletes with regional pain compared with those without symptoms [5]. The authors verified in their study that symptomatic athletes had a significantly greater GIRD with 15° and greater ERG with 10.3° in their throwing shoulders compared with the asymptomatic, pain-free players with a GIRD of approximately 6.7° and ERG of approximately 4.8° [5]. These values found in both groups were below the mean values reported in current studies or reviews [5, 48, 53]. Manske summarized that pathologic GIRD is found (increased risk of injury) when GIRD is greater than 18–20° with a corresponding loss of t-ROM greater than 5° compared bilaterally [53].

Thus, although the values of GIRD and ERG as predisposition factors for the development of symptoms such as pain and structural changes have been extensively reported, they are not completely understood and presumably not fully transferable into the condition seen in team handball athletes [54]. In absolute values, our results for GIRD were below those definitions [23, 25]. A current prospective study could not show any associations between GIRD and shoulder injury [51], and according to Freehill et al. [33] there is no consensus regarding what amount of GIRD is the threshold for an increased risk of injury [33]. In tennis, Moreno-Perez et al. [63] concluded in their study with 47 professionals that limited IR-ROM by itself rather than a GIRD seems to be associated with shoulder pain history, duration of tennis practice, and player's age. They suggested that decreased glenohumeral IR-ROM may be used as criteria for the implementation of prevention and rehabilitation programs in professional tennis players [63]. Freehill et al. [33] commented that GIRD is a measurement of one moment in time. Therefore, an athlete's GIRD can worsen in their throwing shoulder by gaining IR-ROM in their non-throwing shoulder secondary to stretching techniques [33].

As with several types of overhead athletes, muscular strength adaptations can also occur in handball players. Handball players have been shown to have significantly greater concentric and eccentric internal rotation strength compared to a control group. However, these athletes also tend to have more of an imbalance between their strong internal rotators and weak external rotators compared to non-throwing athletes [41, 73]. Not surprisingly, reports have shown that following a simulated handball game, elite adult athletes experience a significant decrease in both internal and external rotation strength [50]. Similarly, handball players who increase their weekly training volume have a subsequent decrease in external rotation strength that is also associated with the development of injury [74]. Although these types of muscular imbalances can be common among handball players, it is clear that they can also result in subsequent injury, particularly with decreased external rotation strength. Edouard et al. [75] showed that youth female handball players with this type of strength imbalance had a 2.5 times higher risk of developing an injury [75]. Similarly, Tonin et al. [76] reported that a group of symptomatic female professional handball and volleyball players presented with less external rotation strength compared to a control group [76]. These findings emphasize the need for general shoulder rotation strength training with a particular emphasis on external rotation.

Scapular adaptations among throwing athletes, such as baseball players, have been well documented and strongly associated with the development of injury. Because of similarities in motion and forces sustained during sport, handball players face similar changes in scapular position and periscapular strength. Ribeiro and

Pascoal [77] reported that the dominant scapula of handball players is more internally rotated and anteriorly tilted compared to volleyball players [77]. Furthermore, both handball and volleyball players present with more dominant scapular anterior tilt than non-throwing athletes. These types of deviations cause the scapula to move laterally around the thorax and are often referred to a forward scapular posture. This forward position of the scapula can result in unnecessary closure of the posterior glenoid-humeral angle causing internal impingement, as well as increased coverage of the superior rotator cuff tendons increasing the risk of subacromial impingement [46]. Moller et al. [74] also showed that handball players with increased training volume experienced scapular dyskinesis and a subsequent increased rate of injury [74]. Because of the tendency for handball athletes to develop scapular dyskinesis, clinicians and coaches should consider strengthening and stretching techniques to promote proper scapular motion and position.

However, in contrast to all current data, a new study by Andersson et al. [65] could not confirm previously mentioned risk factors for overuse syndromes or injuries of team handball athlete's shoulder joints in a sex-mixed prospective cohort study of over 300 elite players, including t-ROM, ER strength, and scapula dyskinesis. The authors partly restricted their results because of methodological considerations concerning reduced reliability in measuring ROM and rating scapula control because of multiple examiners during the surveillance [65]. They concluded that despite the data showed no or only minor associations to shoulder injury risk, therapeutic concepts for IR-ROM stretching, ER-ROM strengthening, and scapula control programs should not be abandoned as a basis for prevention strategies.

4.8 Therapeutic Implications, Strategies, and Prevention

Due to the repetitive nature of throwing motions in the sport and large forces placed on the shoulder during a handball training or match, it is not surprising that numerous adaptations occur in terms of shoulder flexibility, strength, and scapular kinematics. However, when unbalanced, these changes may also lead to a negative effect with increased risk of injury. Therefore, it is critical that coaches and clinicians provide these athletes with strengthening and conditioning programs aimed at minimizing and controlling these adaptations while maximizing sport performance and reducing the risk of injury [78]. Clarsen et al. [51] prospectively followed a group of elite male handball players over the course of a season documenting the occurrence of injuries and their association with scapular dyskinesis, altered shoulder ROM, and glenohumeral strength. These authors concluded that injury prevention programs should include strengthening and stretching exercises aimed at improving shoulder rotational ROM, shoulder external rotation strength, and scapular control.

Moeller et al. [74] showed that players who increased their handball load (e.g., training) by more than 60% in a week (e.g., additional 2–3 handball activities) had less external rotation strength than those players with less change in training. There was no difference for ROM or abduction strength values between any groups. These authors also provided suggested cutoff values that they believed were associated with shoulder injury.

Recommended normative shoulder muscular and ROM ratio according to Moller et al. [74]:

- ER:IR strength ratio dominant arm in 0° rotation = >0.75 considered normal
- ER:IR strength ratio dominant arm in 30° rotation = >0.75 considered normal
- Abduction strength (difference dominant to non-dominant arm) = >0.065 N/kg considered normal
- Total ROM (difference dominant to non-dominant arm) = >−10°
- IR (difference dominant to non-dominant arm (GIRD)) = >−7.5°
- ER (difference dominant to non-dominant arm) = >−10°
- Difference IR dominant to non-dominant arm; difference ER dominant to non-dominant arm = <2.7°

4.9 Introduction to Preventive Strategies and Shoulder Strengthening

Andersson et al. [79] presented the Oslo Sports Trauma Research Center (OSTRC) Shoulder Injury Prevention Programme, which consisted of five exercises targeting glenohumeral IR-ROM, external rotation strength, periscapular muscle strength, thoracic mobility, and the kinetic chain [79]. This supports the previous work by Cools et al. [80] who suggested preventing and treating injuries among similar types of overhead athletes by addressing GIRD, rotator cuff strength with an emphasis on external rotation, and scapular dyskinesis [80]. Examples of the exercises recommended in the OSTRC program consist of sleeper stretches, deceleration throws, and quadruped trunk rotation with a medicine ball (see www.skadefri.no). Detailed descriptions of these exercises are provided in a subsequent chapter in this book. Most importantly, this program has been shown to reduce the prevalence of shoulder injuries among handball players by approximately 28%.

General shoulder rotation and scapular strengthening programs should be incorporated into handball athletes' training programs. Elite female high school handball players who performed a 6-week strengthening program using sling training aides, such as the TRX® suspension trainer (Fitness Anywhere, San Francisco, CA, USA), experienced significant improvements in both internal and external rotation strength [81]. This program consisted of only two exercises, and both exercises utilized a scapular retraction with external rotation motion. Both exercises started with the shoulders in approximately 90° of forward flexion, but for the first exercise, the elbows were fully extended, and for the second exercise the elbows were flexed to approximately 45°. Similarly, Mascarin et al. [82] reported that shoulder internal rotation strength training using resistance tubing resulted in increased muscular power and ball speed among female handball players. Not only can shoulder rotation exercises increase strength and performance, but they can also decrease the risk of injury [82]. Osteras et al. [83] had handball athletes perform simple internal and external rotation strengthening exercises using resistance tubing, as well as push-ups with a plus exercise (exaggerated scapular protraction) and reported reduced shoulder pain from 34% to 11% within the group [83].

The sleeper stretch is a commonly used technique for improving posterior shoulder tightness [84, 85]. The athlete lies on the involved side with the shoulder in approximately 90° of forward flexion and the lateral scapular border against a solid surface (e.g., treatment table, ground, wall). The athlete then passively moves the involved arm into internal rotation until the first point of resistance (Fig. 4.4a). If pain is experienced modifications can be made by placing the shoulder in lower angles of forward flexion or by focusing more on horizontally adducting the arm rather than internally rotating (Fig. 4.4b).

The deceleration throw exercise focuses specifically on strengthening of the shoulder external rotators. The athlete kneels on their throwing side with the opposite hip flexed and the foot flat on the ground. A partner (necessary for the exercise) stands behind the athlete and tosses a light weighted ball over the athletes throwing shoulder (Fig. 4.5a). The athlete is then instructed to catch the ball in approximately 90° of abduction and slow the ball down as the shoulder must eccentrically contract their external rotators to slow the ball from moving forward. As the arm slows the athlete then concentrically contracts the external rotators to pass the ball back to the clinician/coach in the same arc of motion but in a reverse direction (Fig. 4.5b).

The quadruped trunk rotation exercise promotes periscapular muscle activity by facilitating scapular retraction and external rotation as the trunk twists and the shoulder horizontally abducted and externally rotated. Additionally,

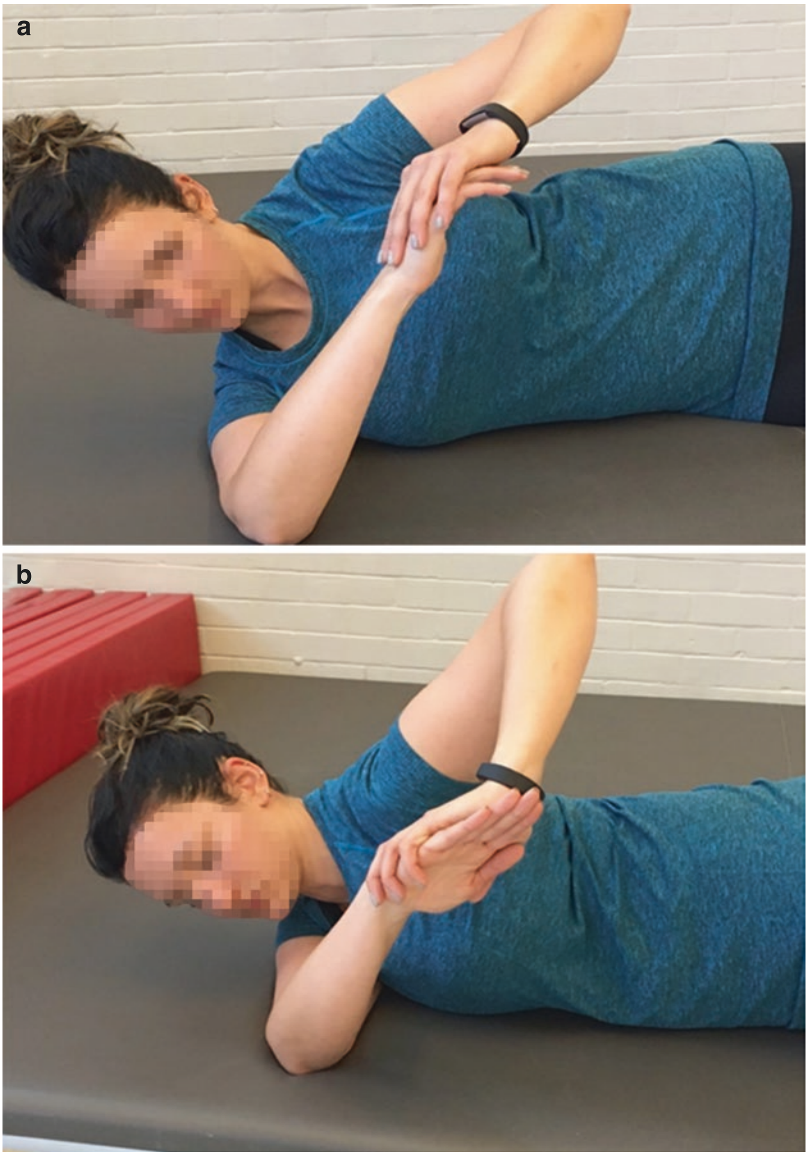

Fig. 4.4 (**a**) Traditional sleeper stretch with internal rotation. (**b**) Modified sleeper stretch with more focus on horizontal adduction

it assists in connecting the kinetic chain by sequentially activating the trunk and upper extremity. It is performed with the athlete resting on their knees and hands, with a light weighted ball positioned under the throwing hand (Fig. 4.6a). The athlete then rotates backward at their trunk moving toward the non-throwing side (Fig. 4.6b).

4.10 Summary

Current data conclude that single clinical examinations of the team handball athlete's shoulder are not valuable for detection of workload or risk assessment concerning injury. As a basis for evaluation, clinicians and physiotherapists should consider bilateral clinical

Fig. 4.5 (**a**) Clinician tosses ball over athlete's shoulder to initiate eccentric external rotation as arm decelerates. (**b**) Athlete concentrically externally rotates shoulder to toss ball back to clinician

examinations of the shoulders and more often in a longitudinal approach (i.e., throughout the competition season) due to specific changes in workload. Currently known risk factors like total range of motion, glenohumeral internal rotation deficit, external rotation gain, or ratio quotients can be calculated and correlated to normative data or current recommendations in the literature. Evaluation of strength, either isometric or isokinetic, in defined rotational actions highly underscores the assessment of workload, adaptions, and risk factors for injury in the shoulder. Both recurrent and bilateral ROM and strength examinations provide the best professional care in the team handball athlete's shoulder.

Preventive therapeutic strategies including functional and compensating strength exercises showed significant reductions in injury occurrence and susceptibility and should be integrated in pre- and seasonal training, as well as during competition.

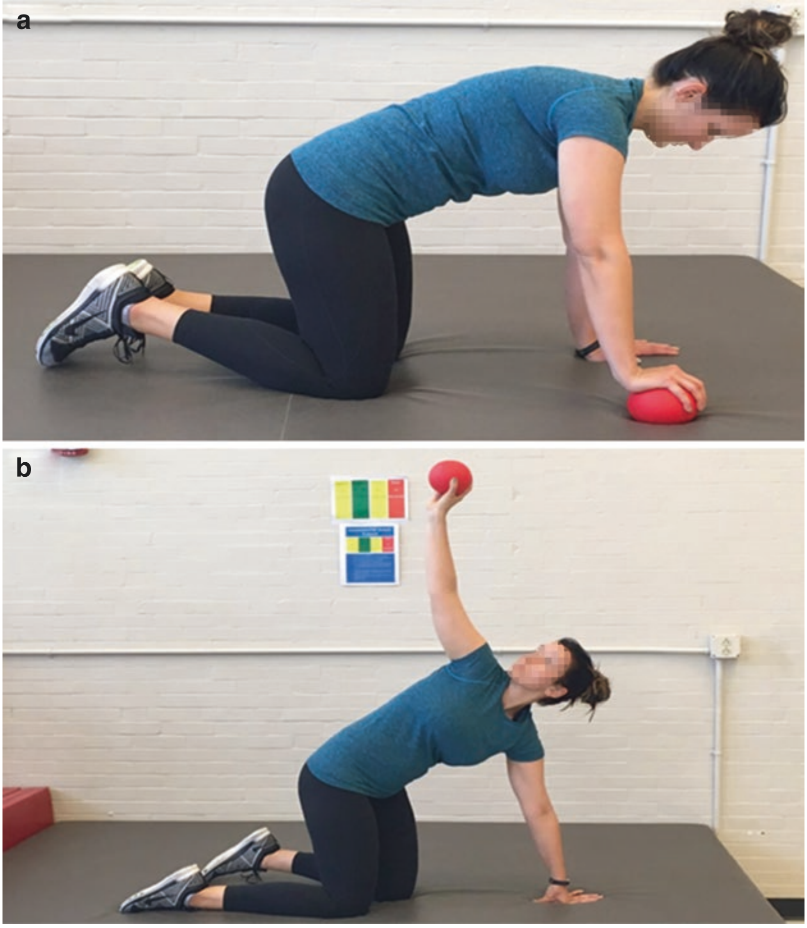

Fig. 4.6 (**a**) Starting position for quadruped trunk rotational rotation. (**b**) Trunk rotation with scapular retraction

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5

Biomechanical Aspects in Handball: Lower Limb

Mette K. Zebis and Jesper Bencke

5.1 Introduction

Traditionally, biomechanical investigations in sports is based on collection of kinematic data, i.e., recordings of joint positions and joint angles with time, and by adding information about force, e.g., from a force plate, kinetic information about joint loading and joint moments can be obtained. The most simplistic way to make a kinematic examination would be to use a video camera and thus get 2D video frames for later visual inspection of, e.g., joint angles over time. This way, measurements of, e.g., the knee joint flexion angles during take-off to a jump shot may be estimated from manual inspection of single video frames or by using software like Dartfish®, Coach's Eye®, Kinovea® or others. However, very few movements in sport are truly 2D, and by only recording data from one camera angle, a lot of accuracy is lost and potential crucial information cannot be precisely deducted. Therefore most biomechanical research in athletic biomechanical performance or injury biomechanics is carried out in a 3D biomechanical laboratory using a sophisticated high-speed camera system, typically using multiple infrared cameras to record the position of reflective markers placed at specific anatomical points on the body of the athlete. By using the information from the different cameras, inherent software will calculate the 3D positions of the reflective markers, and based on a biomechanical marker model, the 3D joint positions can be calculated. Thus, a movement performed in the lab can be displayed graphically and numerically as joint angles and joint moments in all three planes in a matter of seconds. Apart from information about joint angles, joint velocities and joint forces and moments, positions of body segments or centre of gravity, data on muscle activity levels can also be collected synchronously with the recorded movements. This way information on neuromuscular coordination can be evaluated with respect to the specific sports movement and reveal important information about which muscles are contributing to performing a given movement or stabilizing a given joint.

In recent years, other biomechanical measures have emerged in sports research. Muscle and tendon biomechanics may be investigated using strain gauges or dynamometers in conjunction with ultrasound measurements to examine, e.g., the tendon strain or muscle fibre pennation angles as a result of intervention, and in vitro studies on cadavers may directly measure the strain of soft tissues, e.g., the anterior cruciate ligament, during standardized risk movements.

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Although these methods present valid biomechanical data on movements with good accuracy, it may be argued that performing the measurements in a laboratory inherently represents a source of bias, when trying to relate data to real-life sports situations. Therefore, along with the technological development, other biomechanical methods have recently emerged trying to perform measurements in real sports situation. By attaching small high-frequency accelerometers to selected body segments, accelerations and velocities of these body parts can be estimated, and also inertial movement units (IMUs) can be used to obtain data on joint angles during the movement of interest. Future research will reveal the potential of these methods in sports research.

5.2 Biomechanical Performance Evaluation

As discussed in other chapters, multiple studies have investigated physical performance parameters like strength, sprint performance, jump height or jumping power development in handball players based on playing position [1, 2], playing level [1, 2] or after training intervention [3, 4]. However, a striking paucity is evident when searching for biomechanical handball performance studies on physical elements of the games like one-legged jumping or sprint. Training to improve performance is multifaceted; overall leg power is naturally crucial, but in order to direct training interventions more efficiently, it may be beneficial to know more about which muscle groups are most determinant in terms of, e.g., one-legged jumping like in the jump shot or in the sprint start of a fast break. Likewise, studies on the influence of technique of these skills are almost non-existing, as only preliminary data on the importance of the swing leg hip flexion power along with jump leg knee extension power for jump height during jump shots in handball exists (Bencke et al., personal communication). Perhaps this lack of scientific studies on handball lower limb technique reflects and explains coaches' reluctancy towards focusing on the technical aspects of the physical performance, a focus that seems so evident in other sports like, e.g., athletics. While some knowledge and inspiration can be gained from the multiple studies on sprinting or jumping performance in athletics, the lack of studies on handball performance biomechanics leaves room for many studies in this field.

Fact Box
Biomechanical measurements will provide information about joint loading, dominant muscle groups and neuromuscular coordination during subject-specific sports movements like jumping or side cutting.

5.3 Biomechanical Loading of the Knee in Injury-Risk Situations

The scientific focus is markedly different when looking at studies on the biomechanics of lower limb injury risk factors. The ankle and the knee are the two most injured joints accounting for approximately 50% of all reported injuries, and the injury type is typically acute spraining a ligament or damaging other structures in the joint [5–8]. Given the relatively high risk of sustaining a lower limb injury, and the severity of these injuries, much attention has been dedicated to identifying risk factors and testing intervention programmes.

One of the most devastating acute lower limb injuries is rupture of the anterior cruciate ligament (ACL). The anatomical function of the ACL is to add to the passive stability of the knee joint in all three planes [9, 10]. In the sagittal plane forward translation of the tibia is restrained by the ACL. In the frontal plane, the ACL restrains knee abduction movement, and in the transverse plane internal rotation of the tibia is restrained, although some argue that also external rotation, in combination with valgus, may be restrained by the ACL when it is taut around the medial-anterior aspect of the lateral condyle [11, 12]. Also, compression of the knee joint, as may occur when landing on extended knee with large impact ground reaction forces, increases the compression of the knee joint, and due to the posteriorly declining tibial plateau, this may induce an internal rotation which further strain the ACL [13].

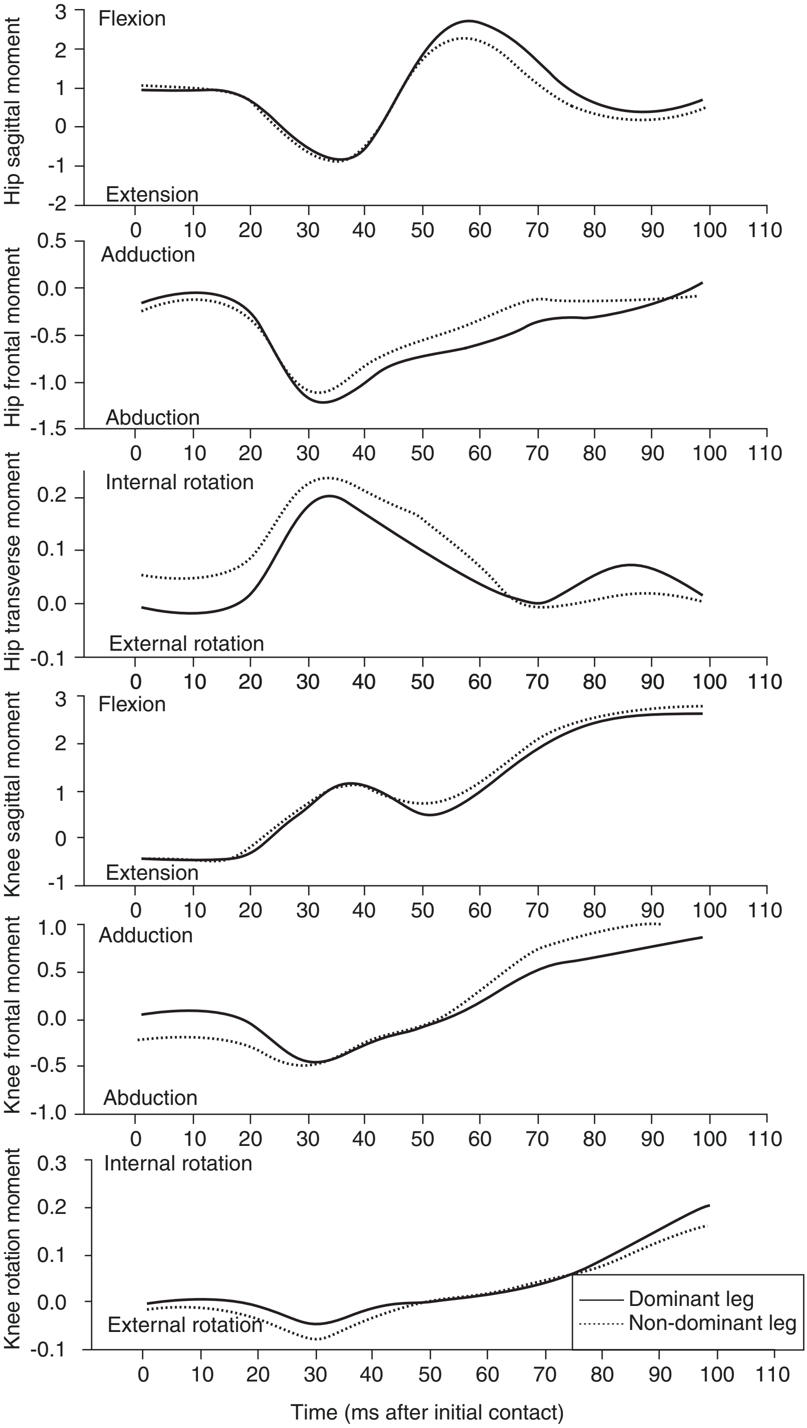

Fig. 5.1 External net joint moments (Nm/kg body mass) for the hip and knee during the first 100 ms after initial ground contact. Solid lines indicate the mean of the dominant leg of all subjects, and dashed lines indicate the mean of the non-dominant leg of all subjects [19]

The biomechanical approach to investigating the mechanistic causes of an ACL injury would then be to analyse the specific movements of the game recognized high-risk situations for sustaining an ACL injury and examine the biomechanical factors potentially affecting the knee joint in a way that would strain the ACL.

In handball, the highest frequency of ACL injuries is seen during noncontact side-cutting movements, followed by landing after shots at goal or passes. These injury patterns are similar in adult elite players [14] and in youth players [6, 12]. The side-cutting manoeuvre in handball is usually very abrupt and explosive, with a very large angular change of direction, and this distinguishes the handball sidecut from other, more forward-oriented, sports-specific movements like landing, drop jumping or side-cutting in, e.g., soccer, which have been investigated in many studies.

Biomechanical investigations of a given sports-specific movement will show how the individual player is loading the lower limb joints during this specific movement. The external joint moments in the sagittal, frontal and transverse planes express loads which potentially may rotate the joint in these directions, respectively. The external knee abduction moment has previously been shown in a prospective study in female basketball and soccer players to be associated with risk of ACL injury during a drop-jump task [15], but a large study in elite handball players did not find any biomechanical factors associated with ACL injury risk during drop jumping [16], and further only very little relation was found between the biomechanics of drop jumping and handball side cutting [17].

Video analyses of ACL injuries occurring in real game situations during side cutting show the injury to occur in situations with less knee flexion, hip internal rotation, knee abduction and knee rotation [12, 18], and computer reconstruction of injury situations also suggests that the injury occurs within the first 40 ms after initial ground contact [18]. Biomechanical investigations of the handball side-cutting manoeuvre reveal a loading pattern which is consistent with these observations and with the anatomical constraints of the ACL. Handball side cutting produces external knee abduction moments peaking within the first 40 ms, coinciding with knee flexion and knee rotation moments and also with external hip internal rotation moments [19] (See Fig. 5.1). An overall interpretation of this body of biomechanical studies on side cutting in handball would be: in the sagittal plane, side cutting demands good control and adequate muscle strength of the knee extensors to allow a certain degree of knee flexion during the movement. The anterior translation which may occur as a result of large knee extensor moments exerted on an extended knee may be counteracted by the hamstrings. In the frontal plane, resisting the external knee abduction moments demands adequate internal knee adduction moments, which biomechanically most likely primarily could be exerted by the medial hamstrings. In the transverse plane, knee joint rotation may be better controlled by strong and active hamstrings. At the hip joint, hip external rotators seem to be important to prevent hip internal rotation and reduce knee joint abduction.

These interpretations may imply that strong quadriceps and hamstrings may be beneficial but a recent prospective study could not corroborate this [20]. The biomechanical analyses of side cutting also suggest that strong and active hip external rotators may be beneficial for stabilizing the hip joint and reducing injury risk, and this has also been shown in other studies [21, 22] and recently also in young elite female handball players (Zebis et al., 2018, personal communication).

Besides directing focus to which muscle groups should be trained, technical recommendations can be provided from biomechanical studies. By reducing the external knee abduction moment during side cutting, a more narrow stance, with less hip abduction, would likely reduce injury risk [23], and studies on athletes from other cutting sports also suggest that reducing trunk lean on the cutting leg side would also reduce external knee abduction moment [24], and further improved trunk stability may also reduce injury risk [25].

The above discussed biomechanical loading patterns are also typical of the less severe overload injuries of the knee, e.g., patella-femoral pain syndrome (PFPS). A reduced ability of the lower extremity to dissipate forces and reduce joint moments during landing and side cutting appears to be an underlying intrinsic factor related to both ACL injury and PFPS. The combination of increased knee abduction moments in conjunction with decreased control of the hip in the frontal and transverse plane increases the stress acting on the tissues and structures of the knee [26]. Thus, prevention programmes developed to mitigate this may be effective in decreasing the prevalence of both these injuries, but for PFPS controlling the work load may be a very crucial parameter. The biomechanical loading of the knee joint during side-cutting and other sports-specific movements is one aspect of determining risk factors and guiding coaches and players towards better and more safe performance. Another aspect is how the subject-specific neuromuscular control of the athletes may help improve the control and resist the external loading of the knee.

Fact Box

Biomechanical risk factors for ACL injury are:

- Landing on an extended knee, which increases the anterior shear forces loading the ACL.
- Increased knee abduction moments potentially straining the ACL.
- Increased knee joint rotation during landing.
- Lack of adequate hip joint control may affect the above-listed factors.

5.4 Neuromuscular Evaluation of Knee Injury Risk Situations

Before explosive movements such as jumping, landing, running and cutting, the involved lower limb muscles are activated before ground contact in order to build up necessary force before the impact. Thus, high hamstring activation during the last 50 ms prior to initial ground contact is essential to produce sufficient hamstring force in the first phase of ground contact. As ACL injuries are reported to occur during the initial phase of ground contact [18], low hamstring activation in this phase may reduce the potential protective effect on the ACL.

Studies on gender differences in muscular activation during jumping or cutting activities have shown a tendency to higher activation of quadriceps and lower activation of hamstrings in females compared to males [27–29]. In a study by Bencke and Zebis, female team handball players were found to display significantly lower hamstring EMG activity in the preactivation period during side-cutting movements than their male counterparts [30]. The lower neuromuscular preactivation of the hamstrings among females in that study supports the notion that female athletes display a different neuromuscular strategy in situations where ACL injuries occur [30]. Furthermore, the hamstrings have been shown to contract concentrically during the initial phase of ground contact during the sidestep cutting manoeuvre, and thus the hamstrings may not be able to produce the same force with the given neural activation as with an isometric or eccentric contraction during initial ground contact [31] (Fig. 5.2).

In a study by Zebis et al., neuromuscular screening by EMG was used to predict future ACL injury in currently non-injured female handball and football players [32]. The study found that currently non-injured players with reduced medial hamstring muscle preactivation during side-cutting movements are at increased risk of future noncontact ACL injury [32]. Thus, ACL injury prevention should include preventive exercises that target the medial hamstrings.

By the use of EMG, it is possible to evaluate and identify the neuromuscular stimuli during execution of different training modalities. Thus, EMG evaluation allows us to gain knowledge about the muscle activity pattern during exercises used in both ACL prevention and rehabilitation interventions. Common strength exercises for the lower limb muscles such as squats, leg presses and knee extensions show high levels of muscle activity in the quadriceps along with a preferential higher lateral compared with medial hamstring muscle coactivation [33]. Focusing primarily on these exercises may predispose for knee injury. Importantly, Zebis et al. found that specific therapeutic exercises targeting the hamstrings can be divided into medial hamstring dominant (e.g., Kettlebell swing and Romanian deadlift) or lateral hamstring dominant (e.g., supine leg curl and hip extension) hamstring exercises [34]. Thus, the use of an EMG can provide guidelines and thereby optimize injury prevention in sports like handball.

Fact Box

Neuromuscular risk factors for ACL injury are:

- Reduced activity of the medial hamstrings during side cutting
- Reduced strength or activity of the hip external rotators

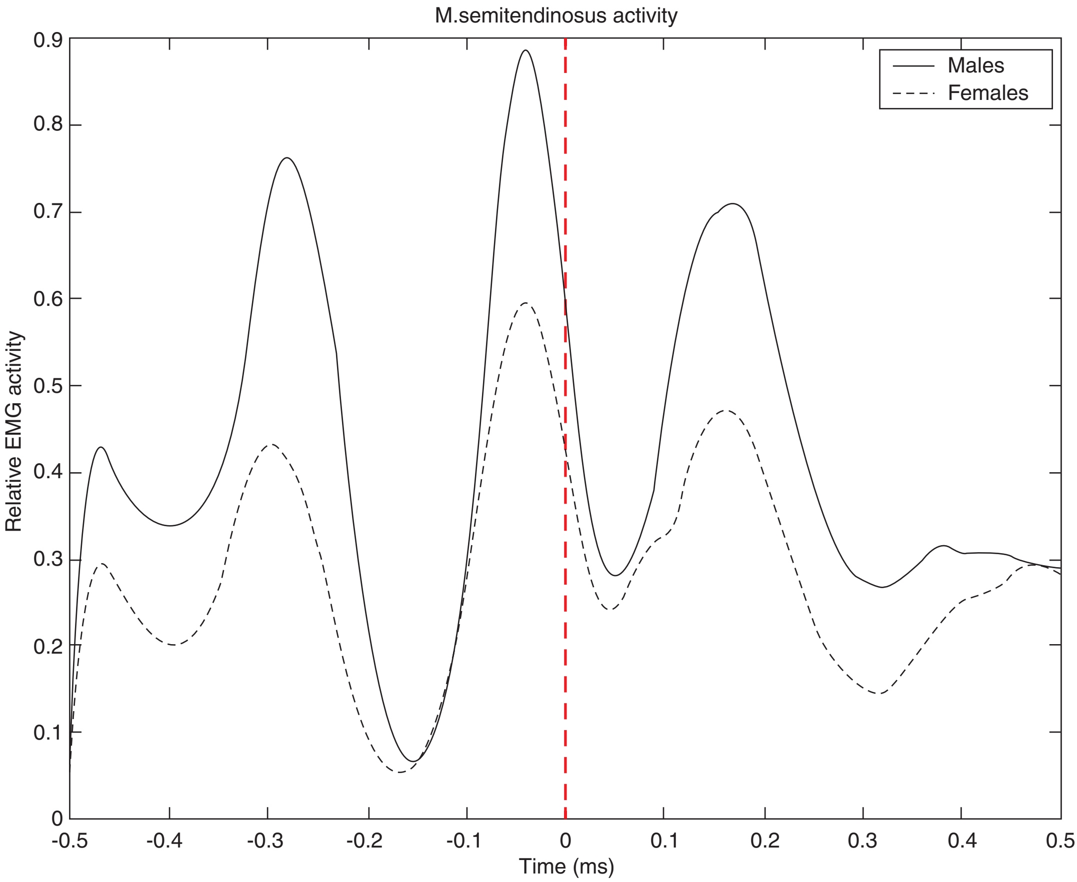

Fig. 5.2 This figure illustrates an example of the difference between female and male handball players in hamstring preactivation during a side-cutting manoeuvre. The vertical dotted line represents ground contact. The illustration is kindly provided by Jesper Bencke

5.5 Biomechanical Risk Factors for Ankle Injuries

Although the severity of ankle sprains does not resemble that of the ACL injury, ankle sprains are frequent and may effect performance for a considerate time. The injury mechanism is predominantly an excessive inversion of the rear foot or a plantar flexion combined with adduction of the forefoot [35]. The greatest risk factor of ankle sprain is a prior ankle sprain sustained during the previous year [ECCS Position Statement 2009]. There is evidence that an ankle sprain negatively affects neuromuscular control, most likely due to trauma to mechanoreceptors of the ankle ligaments reducing proprioceptive capacity [36]. As a result, a previously injured ankle is exposed to an increased risk of reinjury [37], and primary injury prevention seems important. Many studies have shown a relation of reduced balance and increased risk of ankle injury [38], which may imply that the proprioceptive control of the ankle joint is reduced in athletes susceptible to ankle injury. Indeed, reduced proprioceptive sense has also been shown in patients with functional ankle instability (FAI) [38]. With respect to muscle strength, previous studies are less conclusive. It seems logical that strong evertors would be reducing the risk of injury but current data does not support that assumption [39]; however some studies show lower preactivation of the ankle evertors before landing from a jump in athletes with FAI [40]. Prevention programmes for ankle sprains are effective [37, 38] and should include exercises for balance, preferably, dynamic exercises which may be more effective [38], likely due to the increased activity levels of ankle evertors compared to more static exercises [41].

In summary, biomechanical measurements of the lower limb during injury-risk situations have improved the understanding of risk factors and may thus set the direction for preventive measures or improve rehabilitation regimes.

For prevention of either acute or overload knee injuries, optimal biomechanical control of the lower limb during landing and side cutting is important. Being able to control the hip joint to avoid internal rotation during these loaded situations in handball and being able to absorb the high-impact forces by increasing the knee flexion during landing may reduce the risk of straining the ACL through increased frontal plane loading or anterior shear forces. Proper hip external rotator strength and adequate activation of medial hamstrings during risk situations may further protect the knee joint from external detrimental forces. This will be further elaborated in later chapters on exercises and implementation of preventive programmes.

Fact Box

Coaches should teach handball players to:

- Land on more flexed knees
- With a more narrow stance (less hip abduction) with the knee in line with the hip and foot

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6

Throwing Biomechanics: Aspects of Throwing Performance and Shoulder Injury Risk

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6.1 Introduction

Biomechanics is the scientific discipline of describing movements and loading of joints and soft tissue. Biomechanics typically utilises motion analysis to obtain the kinematics and kinetics in order to quantify human movement. Kinematics quantifies the motion of a system (i.e., position/velocity/acceleration), whereas kinetics quantifies the forces and torques that cause these motions. As such, it may provide insight into the technique of sports performance and information about mechanisms of injury. In team handball, being able to throw with high quality is crucial for performance, and investigating the biomechanics of throwing will elucidate the specific timing and segmental coordination (i.e., technique) characterising the optimal throw. At the same time, in combination with knowledge of functional anatomy, biomechanical investigations may also reveal loading patterns or nonoptimal coordination which may increase the risk of injury. Information about both optimal throwing technique and injury risk factors is important for the athlete, coach and health-care personnel.

6.2 Biomechanical Aspects of Throwing Performance

In team handball competition, the throwing movement finalises the offensive action. To succeed in an attempt to score a goal, a team handball player must maximise the precision of the throw as well as ball velocity. It is well known that team handball players use different throwing techniques based on their playing position and it is dictated by the movements of the opposing defensive players. In competition, 73–75% of all throws during the game constitute jump throws, followed by the standing throw with run-up (14–18%), penalty throw (6–9%), diving throw (2–4%) and direct free throw (0–1%) [1]. These different throwing techniques are used to increase the horizontal velocity (run-up), making it difficult for the defensive player to tackle and potentially enabling a higher ball velocity.

In general, all sports that involve overarm movements with a high endpoint speed, an optimal performance (maximal ball velocity) is obtained through a specific progression (timing) of acceleration and deceleration of segmental movements,

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as suggested by Herring and Chapman [2]. The progression of segmental motion displays initial forward motion of a proximal segment, while more distal segments rotate backwards (i.e., like the upper arm extends and "lags behind," when the trunk begins the forward rotation). The distal segments will be decelerated by eccentric contraction of the agonist muscles and subsequently accelerated forwards by concentric contraction of the same muscles [3], with the muscles thus performing a stretch-shortening cycle. If this progression of segmental movements occurs in a proximal-to-distal order, it facilitates a transfer of momentum from the pelvis (or lower limb) through the trunk to the throwing arm, thereby enabling higher velocities in throwing movements [3].

In team handball throwing, a proximal-to-distal sequence was also found in elite and experienced players (Fig. 6.1), however not fully complying to this segmental rotation order in the final part of the throw [4–8]. It was shown that maximal pelvis rotation angular velocity occurred before trunk rotation and trunk flexion angular velocity followed by the elbow extension and shoulder internal rotation angular velocity. The observation that the maximal elbow extension occurred before the maximal shoulder rotation angular velocity facilitates a higher ball velocity, as the earlier extension of the elbow reduces the moment arm for the shoulder internal rotation allowing a higher internal rotation angular velocity and thereby leading to a higher ball velocity [9]. As shown in Fig. 6.2 this characteristic movement coordination was found at all experience levels; however, less experienced players were not able to produce a proximal-to-distal sequencing from the pelvis rotation to the shoulder flexion compared to experienced and elite players. Not only in timing (Fig. 6.2) but also in the maximal trunk flexion and rotation angular velocity significant differences were found between elite and low-level players [10]. Furthermore, to optimise throwing velocity, it was found that the elbow extension and shoulder internal rotation velocity starting from a maximal external rotation angle are the two main parameters related to overarm throwing velocity in team handball [5, 11]. These results have shown that the movement of the trunk and an optimal timing of segmental accelerations are essential in team handball throwing.

Comparing different throwing techniques in team handball, it was found that ball velocity was significantly impacted by the run-up and the pelvis and trunk movements. Depending on floor contact (standing vs. jump throws), team handball

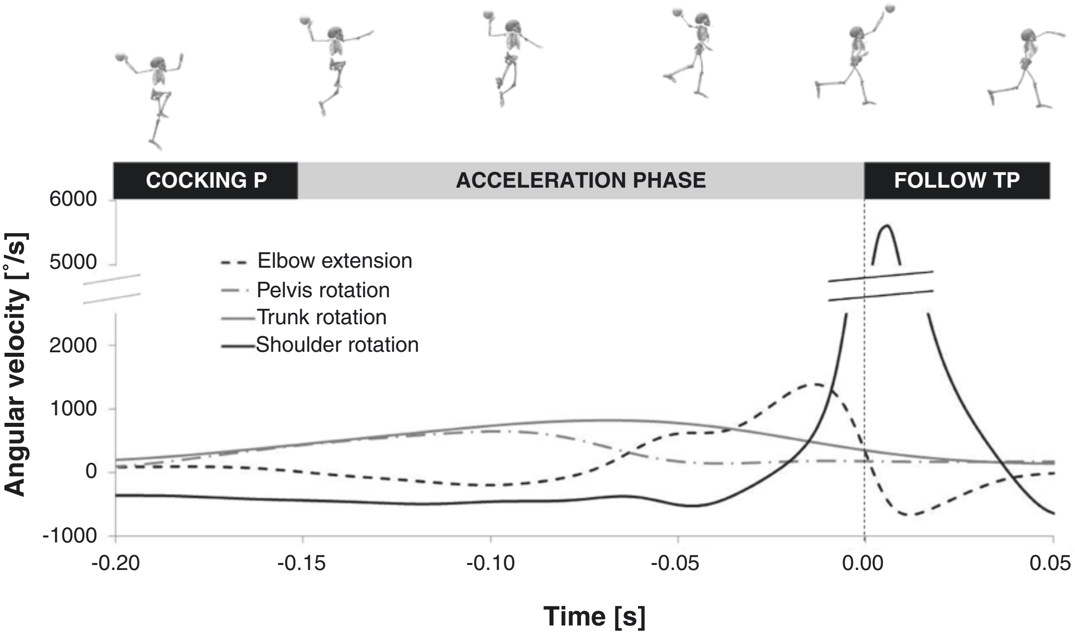

Fig. 6.1 Pelvis and trunk rotation, shoulder internal rotation and elbow extension angular velocity in the team handball jump throw

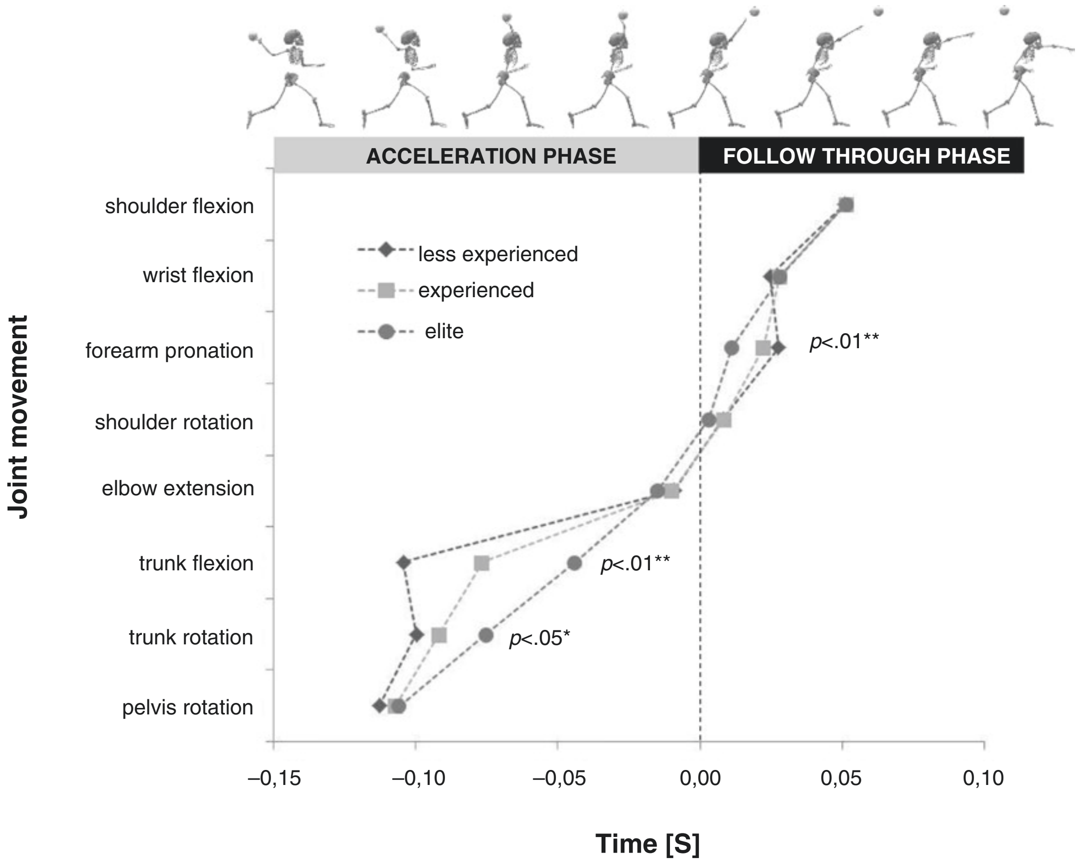

Fig. 6.2 Mean timing of occurrence of maximal joint angular velocities in the standing throw with run-up in less experienced, experienced and elite team handball players. Significant differences between two joints and skill groups: *$P < 0.05$, **$P < 0.001$ and **$P < 0.001$

players used two different strategies (lead leg brakes the body vs. opposed leg movements during flight) to accelerate the pelvis and trunk to yield differences in ball velocity [12]. Comparing different arm positions (overarm vs. sidearm), it was found that the different position of the hand at ball release was primarily caused by different trunk flexion and tilt angles [10]. However, in all different throwing techniques (standing vs. jumping and/or run-up, overarm vs. sidearm), elite and experienced players were able to adapt their throwing movement to the different conditions to perform an optimal proximal-to-distal sequencing and similar throwing arm movements [8, 12–15]. These optimal proximal-to-distal sequencing and similar arm movements were also found in overarm movements in other sports like tennis, volleyball, and baseball [3, 4].

When examining differences between male and female players, several studies have shown that male players are able to throw faster, although the ball in male team handball is 0.1 kg heavier [16–18]. These differences in throwing velocity were mainly caused by the height of male compared with female players. Male players are on average 0.1 m taller, the distance between the shoulder and finger at ball release is 0.06 m longer, and the segmental length of the forearm with hand is 0.04 m longer [19]. Another variable that could explain sex differences in throwing velocity was the fat-free mass. Male elite handball players have generally more fat-free mass than female players and were therefore able to throw faster because of the subsequent higher muscle mass [18].

Besides dividing the different throws based on arm position or after run-up or jumping, it is possible to identify all types of handball throws by their wind-up: a circular or whip-like wind-up and that these different wind-up have different biomechanical characteristics [20]. Higher ball velocities were found with the circular wind-up than with the whip-like wind-up. These were mainly caused by a significantly higher maximal joint movement velocity of the pelvis and pelvic tilt using the circular wind-up than with the whip-like wind-up. Since the rest of the joint movements showed no significant differences between the two wind-up techniques, the pelvis and pelvic tilt resulted in a higher maximal velocity of the endpoints of the hip and shoulder segments of around 0.5 m/s each and a higher ball velocity of 1 m/s. However, timing sequence of initiation and maximal angular velocity between the two wind-ups was very similar [20] (Fig. 6.3).

The main difference in the wind-up techniques was how the arm was moved backwards in the cocking phase, and naturally the kinematics in this phase was expected to be different. Minimal shoulder abduction angle was higher with the whip-like wind-up, because the elbow is raised to the side from the two-hand phase to the one-hand phase and not downwards backwards like in the circular movement. Furthermore, in the circular wind-up the maximal angle of the shoulder flexion and the trunk tilt forwards were higher than with the whip-like wind-up during the cocking phase. These increased angles may stretch the arm, shoulder and abdominal muscles more extensively and can build up more tension early in the movement, i.e., an enhanced counter movement between trunk and upper extremity occurs [11]. This was also shown by the significantly higher pelvis and upper torso rotation with the circular wind-up. In the whip-like wind-up the ball was directly moved upwards and backwards, and this resulted in a significantly higher peak external rotation angle of the shoulder. These increased angles during the arm-cocking phase may cause increased forces around the elbow and shoulder joint. Furthermore, total throwing time was longer with the circular wind-up. This resulted in a longer cocking phase since the timing of the maximal external rotation of the shoulder with the circular wind-up was significantly

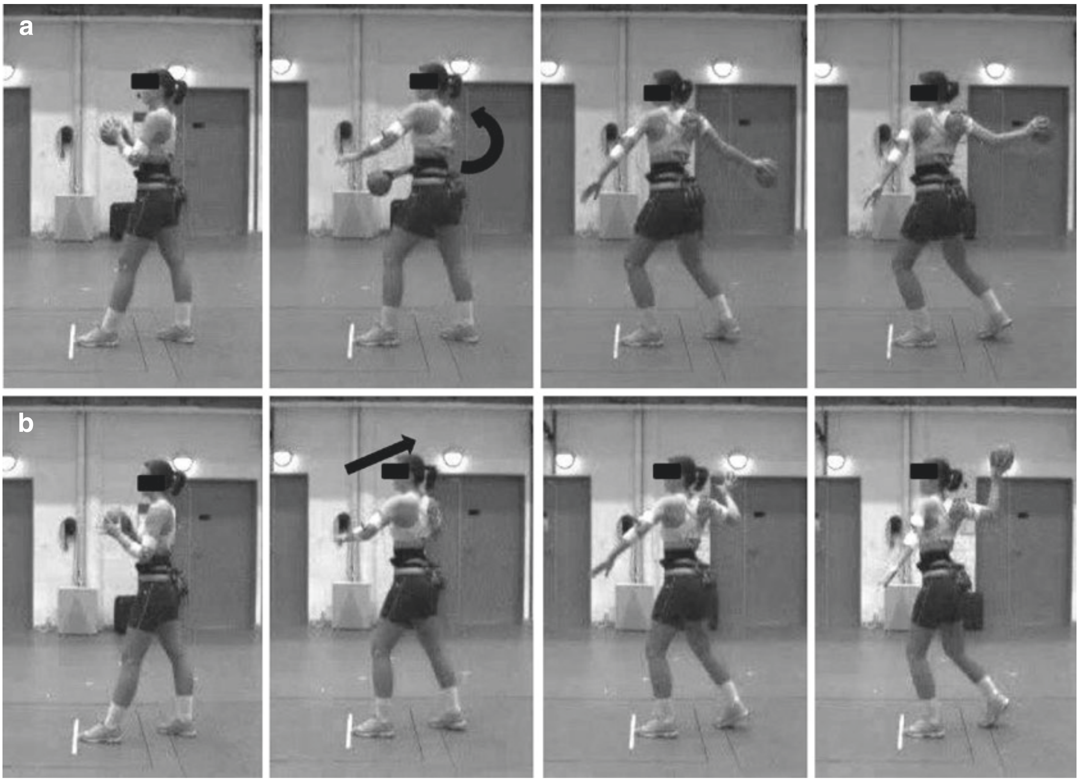

Fig. 6.3 (**a**) An example of an overarm throw with a circular wind-up throwing movement. (**b**) An example of an overarm throw with a whip-like wind-up throwing movement in team handball (adapted with permission [20])

closer to ball release. Also the initiation and maximal ball acceleration occurred closer to ball release with the circular wind-up. As the maximal acceleration was closer to ball release, this resulted in a higher ball release velocity with the circular wind-up. As discussed above, handball throwing is a very technical and forceful skill. The nature of the game constantly challenges the ability of the player to vary the way of throwing either hard or soft, with run-up or jumping and with different arm positions or wind-up, which inherently also challenges the technical skills and strength of the individual player. Training to optimise technique in a variety of throwing types seems essential for the top-level player.

Fact Box

Biomechanical Aspects of Throwing Performance:

> Ball velocity in team handball is strongly influenced by an optimal proximal-to-distal sequencing, optimal trunk movement, maximal arm rotation and an optimal adaptation to different conditions (standing vs. jumping with or without run-up, different arm positions, tackling from the opposing defensive player). Consequently, coaches should focus on trunk stabilisation and an optimal throwing technique before strength training to improve performance.

6.3 Biomechanical Injury Risk Factors of the Shoulder

The described biomechanics of performing an optimal hard throw also imposes a risk of overload injury. When looking at the potential injury risk elements of a throw, two main phases are evident as the instants involving the highest muscle forces and then potentially the highest risk of injury: (1) The cocking phase, where the initial backward rotation of the trunk and shoulder horizontal extension and external rotation is decelerated and immediately succeeded by a forceful trunk forward rotation, shoulder horizontal flexion and internal rotation, and (2) the deceleration phase after ball release, where the forceful forward trunk rotation, humeral flexion and internal rotation must be decelerated quickly. These elements of the throwing technique depend heavily on muscle strength of all involved muscle groups, optimal neuromuscular coordination, adequate range of motion and stability of the proximal segments [3]. Reduced capacity or internal imbalance in any of these parameters may increase injury risk.

The biomechanical foundation for exerting high forces around the glenohumeral joint in order to accelerate the ball is a solid proximal base of the muscle attachments to accelerate the distal segment. That is, a stable scapula is necessary for the glenohumeral rotators to internally and externally rotate the upper arm with adequate force, and if descending through the kinematic sequence of rotation described above, the thorax needs to be stable to adequately allow the scapula-stabilising muscles to control the scapula, etc. This exemplifies a kinetic chain where the transfer of momentum from the proximal segment to the distal segment is very dependent on the strength and optimal neuromuscular control of the proximal segment, starting with a good core stability as also described by Kibler et al. [21] and having the optimal coordination of segmental rotations in order to reduce excessive loads in the shoulder. Studies in baseball pitchers have shown that nonoptimal coordination of pelvic and trunk rotation influences the shoulder joint loading [22, 23] underlining the importance of the correct kinematic intersegmental coordination to reduce the stressful loading of the shoulder. The same mechanism must also be considered when performing variations of the standard throw. In handball, a very diverse range of throwing techniques is displayed, and the whip-like wind-up technique discussed in the previous section is typical of the frequently used, fast-performed throw with the ipsilateral foot in front. Performing these alternative, quickly performed, throws may increase the chance of getting the ball past the defender due to the element of surprise, but it may also increase the injury risk by placing more stress on the shoulder joint as this technique involves less rotation of the proximal segments to initiate the acceleration and shorter time for acceleration of the distal segments and thus increasing the force needed to reach the same approximate ball velocity [20].

As mentioned above, adequate muscular strength and optimal neuromuscular activation is also important, both for performance and injury prevention. By creating a solid foundation for optimal control of the distal segments, increased core and pelvic strength and stability may reduce shoulder injury risk [24], and in handball it is shown that performance may be improved by training core stability [25, 26]. Around the glenohumeral joint, reduced muscular strength of the external rotators has been found to increase the risk of shoulder injury in baseball [27]. This association was also found in adult male handball players [28, 29]; however, it could not be confirmed in a recent study in mixed-sex handball players [30]. Biomechanically, the shoulder external rotators may play a role as stabilisers during the cocking phase, but during throwing the forceful deceleration of the internal rotation after ball release depends largely on the shoulder external rotator muscles. Lack of strength may result on greater stress on other soft tissue on the posterior side of the shoulder due to a lesser ability to dynamically break the internal rotation movement.

Another biomechanical aspect of shoulder injury risk is the range of motion of the glenohumeral joint. Rotational range of motion is an important factor for throwing performance, and increased maximal external rotation is often observed in the throwing arm of handball players, as well as other overhead athletes, compared to the non-throwing arm. It is argued that increased maximal external rotation angle in the overhead athletes allowing increased arm cocking might have a positive effect on ball velocity, as it allows a larger internal rotation motion to accelerate the ball [13]; however, a recent study could not correlate clinically measured external rotation RoM with either ball release velocity or measured maximal external rotation during throwing in handball [31]. Some of the observed increased maximal external rotation may be attributed to increased humeral retroversion, probably due to the torsional stresses from throwing on the growing bone [32, 33], thus also displaying a glenohumeral internal rotation deficit (GIRD), without any change in the total rotational range of motion. However, studies in baseball show that if GIRD is accompanied by a reduced total rotation ROM, shoulder injury risk is increased [34]. In the literature, consensus on the importance of GIRD and total ROM as independent risk factors for injury is not yet established; however, in male elite handball players, Clarsen et al. [28] found a slightly increased risk of injury with reduced total rotational ROM, but no significant association of GIRD and injury risk, but on the other side, Andersson et al. [30] could not confirm these risk factors in a large group of mixed-sex handball players [30]. Besides the increased retroversion, a biomechanical explanation of a reduced total range of motion may be a tightness of the posterior shoulder joint capsule and muscles [35, 36], probably caused by the cumulative loads of the deceleration phase in repetitive throwing [32].

Most studies on shoulder rotation have reported the angles of humeral rotation in relation to the planes of the thorax with the scapula in a fixed position, but in reality the humeral rotation occurs with respect to the scapula, which in turn moves with respect to the thorax [37]. Therefore, the positioning of the scapula is crucial when discussing which degrees of rotation that may be increasing the injury risk. For instance, an external rotation of 140° in abduction with respect to the thorax may stretch the joint capsule much more with an anterior tilted scapula, than if the scapula has moved with the external rotation by posterior tilting around a transverse axis. The importance of the scapula positioning has been shown in cadaver studies during a simulated cocking phase, where maximal external rotation, in combination with less scapula upward rotation and increased scapula internal rotation, increases the risk of impingement [38]. These cadaveric observations direct the attention to how optimal scapula kinematics should be during the cocking phase of throwing, i.e., optimise posterior tilting, and ensure adequate upward rotation and sufficient external rotation of the scapula. Adequate muscular strength and neuromuscular activation of the muscles securing this optimal positioning during throwing is important, and later chapters will discuss in detail which exercises are important for the rehabilitation of nonoptimal scapula kinematics. But in order to investigate which factors may influence the scapula positioning during the injury situation, i.e., the throwing situation, biomechanical measuring of the scapula may be a means of investigation. However, measuring the scapula kinematics during throwing is a challenge, because kinematic tracking of the scapula is difficult due to the explosive nature of throwing and the fact that most of the scapula move under the skin and only the acromial plateau is suitable for marker placement. Thus, relatively few studies on the 3D biomechanics of the scapula during throwing have been performed. Only two studies have investigated the scapula kinematics during handball throwing showing that at the instant of maximal arm cocking, i.e., the instant of great impingement risk [38], the scapula was at the highest level of external rotation, upward rotation and posterior tilting in order to biomechanically accommodate the need for stability (Bencke et al., unpublished; [39], which corresponds well to the findings in baseball [40, 41]. During handball practice many throws of different exertion are performed, and fatigue may be a factor affecting the control of the scapula. Several studies have observed abnormal scapula kinematics as a result of fatigue during other, more simple, upper limb motor tasks (e.g., [42]), but Plummer and Oliver [39] find no change in scapula kinematics in handball players after localised fatigue induced by medicine ball throwing. In contrast, new data suggests small significant reductions in scapula upward rotation and posterior tilting at the instant of maximal humeral external rotation during throwing in handball after a fatiguing protocol simulating handball practice throwing (Bencke et al., unpublished data). Although these data may only add some suggestions for mechanical explanation of factors contributing to shoulder injury risk, a larger prospective study in handball has also demonstrated the scapula control as a risk factor for overuse shoulder injuries. Clarsen et al. [28] have shown prevalence of scapula dyskinesis among players with shoulder injury in male elite handball players [28]; however, in a follow-up study in mixed-sex population of handball players, these results could not be confirmed [30]. The findings by Clarsen et al. [28] and Andersson et al. [30] are limited by inclusion of both new and existing shoulder problems at study start [28, 30]. As the authors recognise, causation cannot be assumed without solely focusing on new shoulder problems. The identified associations between scapular control, decreased TROM, reduced external strength and shoulder problems in these studies might just as well have resulted from the existing shoulder problems as they may be a risk factor for development a new shoulder problem. Based on the many chronic cases seen in these studies, the former scenario is more likely than the latter.

This is important in an injury preventive perspective, because for a modifiable biomechanical risk factor to be preventable, it must be established whether or not the association between the risk factor and injury represents a causal relationship [43].

Fact Box

Biomechanical Risk Factors in Throwing:

- The correct proximal-to-distal sequence will reduce loading of the shoulder and thus reduce the risk of overload injuries.
- High dynamic core strength and stability will reduce injury risk by facilitating optimal rotation sequence.
- Optimal scapula control is crucial to reduce risk of impingement and other overload risk factors.
- Facilitating adequate posterior tilt, external rotation and upward rotation through sufficient ROM and optimal scapula muscle strength and coordination is recommendable.
- Strong external rotators and sufficient total ROM will reduce injury risk related to the deceleration phase of the throwing.
- Managing progression of throwing load by close supervision throughout the season will reduce risk of injuries due to overload.

6.4 Aetiology and Mechanisms of Shoulder Injury

To facilitate a better understanding of sports injury aetiology, causal models, such as the original multifactorial model [44] and its subsequent revisions [45, 46], have been introduced as overall visual models to provide a broad conceptualisation of aetiology for sports injury in general. The model by Meeuwisse acknowledges that exposure to injury results from a combination of being subject to different risk factors and, through preceding cycles, participating with these risk factors being present [46]. Based on this premise, handball participation must be considered as primary exposure for injury, while other factors, for instance, biomechanical factors, influence the level of handball participation a player can tolerate before injury occurs [47].

Risk factors related to participation, in the literature also described as external training load, may represent step count, distance run, throws and/or time spent practising sport in both training and competition [48]. With regard to the association between training load and shoulder injuries in overhead sports, significant associations between the absolute throwing workload defined as the total number of self-reported throws or pitches the week before injury have been reported in baseball and cricket [49–52]. These findings support the importance of training load in shoulder injury development and have already formed the basis of preventive throwing regulations for youth baseball pitchers [53].

A drawback to the use of absolute load changes is that they do not take the players' changing cycling of injury, participation and other risk factors into account. For example, an association between more than 75 throws and risk of shoulder injury has been reported in the literature [50, 51, 54]. However, there is a possibility that the recommendations of the number of throws might be different at the beginning of the study (which could be the preseason or the start of the season) than in the mid-season. In addition, the number of throws tolerated is likely to be different for experienced players compared to inexperienced players or when a player returns to sport after injury. To encompass these changing factors, relative training load is likely to provide a more applicable measure of the external load.

Sudden increase in training and competition load relative to either the preceding week or 2–4 preceding weeks has been associated with injury in various sports in the literature [55–57]. Only one published study has undertaken research into the relationship between relative training load and injuries in youth handball players [29]. The findings from this study demonstrated that the shoulder injury rate was nearly twice as high in the week following a 60% or greater increase in handball load (hours of competition and training) when compared with increase in handball load <20%. Additionally, Møller and coworkers [29] examined how athlete characteristics modified the association between training and shoulder injury rate. This analysis differed from previous mentioned and traditional analyses, treating handball load as the primary exposure and biomechanical variables as effect measure modifiers. The findings showed that an effect of a moderate increase between 20% and 60% in handball load was exacerbated by the presence of reduced external rotational strength or scapular dyskinesis and that reduced shoulder external rotational strength also exacerbated the effect of large increases in handball load above 60%. Concerted efforts should, therefore, be made to avoid rapid increases in handball load. This is particularly important for players with scapular dyskinesis and reduced strength, because players with these certain characteristics may be more vulnerable to shoulder injury already at a moderate increase in handball load [29].

In summary, this chapter has described that a key element of good throwing performance is the optimal proximal-to-distal rotation sequence enabling the segments to build up ball velocity efficiently without overloading specific joint structures, typically around the shoulder; consequently focus on improving throwing technique is important for performance. Changing throwing technique both in terms of different arm positions and different wind-up techniques may give some functional advantages in the game situation but may also increase the loading of soft tissue around the joints and thus injury risk. Furthermore, the chapter has discussed the importance of rotational strength and range of motion around the shoulder, as well as distinct biomechanical parameters important for optimal kinematics of the scapula. Finally, we have discussed the association between these parameters and shoulder injuries, as well as how some of these factors influence the associations between weekly increases in training load and shoulder injury rates in handball. In short, throwing is the key factor for injury, but optimal strength, range of motion and scapula control will reduce the injury risk.

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Nutrition and Hydration for Handball

7

Jorge Molina-López and Elena Planells

7.1 Introduction

Achieving optimal athlete nutrition presents one of the greatest challenges in developing strategies favoring the adaptations that occur as a result of training and competition. Acquiring the necessary knowledge to determine athletes' needs will play a fundamental role in determining nutritional requirements in response to the increased demands from exercise. As a result, the role of the dietitian-nutritionist is increasingly present in the world of sports. At this time, establishing nutritional policies and procedures regarding nutritional status, hydration guidelines, supplementation strategies, and injury prevention is critical, since optimal adaptation to meet the demands of repeated training sessions requires a proper diet in terms of quantities and types of nutrients. Although scientific evidence on a set of dietary recommendations or nutritional requirements during exercise has been described [1–3], in sports such as handball, it is generally accepted that athletes need to maintain a diet consistent with the recommendations for macro- and micronutrients in the general population to maintain good health status. Therefore, there is a need to understand additional nutritional strategies that handball players can implement in order to enhance nutritional and hydration requirements throughout the handball season. This could result in favoring the physiological response to handball, which may lead to better adaptation to exercise and an improvement in exercise performance.

7.2 Role of the Sports Nutritionist

The science and practice of sports nutrition is continually evolving, aided by an enthusiastic research base, the publication of peer-reviewed journals dedicated to sports nutrition, and the development of consensus statements from expert groups including the International Olympic Committee (IOC) and American College of Sports Medicine (ACSM) [4].

The relationship between nutrition and sports performance has become increasingly important due to the rise in the number of athletes and active people that need qualified professionals to optimize their food choices, thus supporting exercise performance and health status. Based on the previous assumption, the role of the nutritionist in sports such as handball will require knowledge of the sport-specific physiological demands of training and competition to be able to implement dietary recommendations and strategies within the framework of a multi-professional sports team. An individual approach is needed to meet each athlete's nutritional and hydration needs,

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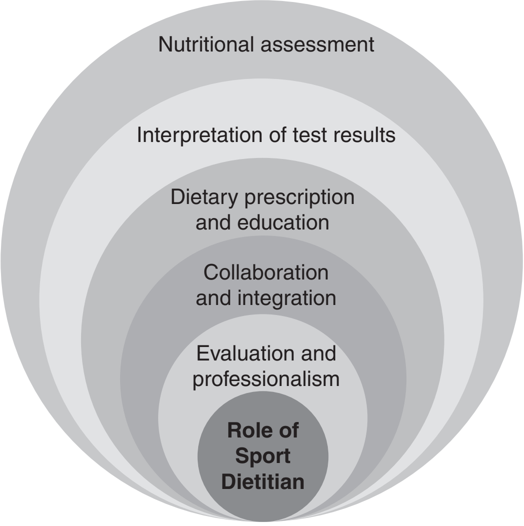

Fig. 7.1 Sports dietitian roles

assessing nutritional status and guiding and advising based on the evidence for health and exercise performance in athletes, sports organizations, and physically active people.

In this sense, organizations like the Academy of Nutrition and Dietetics [5] revised the Standards of Practice and Standards of Professional Performance of Registered Dietitian Nutritionists in Sports Nutrition and Dietetics in 2014 to put into practice and manage safe and effective nutritional intervention and strategies for improving health and exercise performance. Figure 7.1 shows the main roles of sports dietitians. The scope of practice in nutrition includes the code of ethics and the roles, activities, and regulations that sports nutritionists perform [6].

7.3 Energy Metabolism

Handball is classified within the team sports known as its intermittent nature of combining efforts at low and high intensity, with an energy source that alternates energy systems during sports [7, 8]. Current studies [9, 10] have shown that elite handball players are highly active and engage in a number of intense physical confrontations (tackles, screenings, holding, and blocks) with opponents, suggesting a need for high levels of muscle strength, explosive muscular actions, and high mobility. Due to their short-duration, high-intensity, and repetitive nature, it is likely that a number of these technical actions will impose high demands on both anaerobic and aerobic energy production, which depend on carbohydrates (CHO) as the main source of energy [11].

The energy systems used during exercise for muscle work include the phosphagen and the glycolytic (both anaerobic) and the oxidative (aerobic) pathways. The phosphagen system is used for short (lasting a few seconds) high-intensity events. Adenosine triphosphate (ATP) and creatine phosphate provide the readily available energy present within the muscle. The amount of ATP present in skeletal muscles (≤5 mmol/kg wet weight) is not sufficient to provide a continuous supply of energy, especially at high exercise intensities. Creatine phosphate is a reserve of ATP in muscle that can be easily converted into sustained activity for 3–5 min [12]. The amount of creatine phosphate available in skeletal muscle is approximately four times greater than ATP and is therefore the primary source of energy used for high-intensity and short-duration activities such as short-term and explosive actions in handball [9]. The anaerobic glycolytic pathway uses muscle glycogen and glucose that are rapidly metabolized anaerobically through the glycolytic cascade. Thus, this supports events lasting 60–180 s. Table 7.1 shows a summary of some of the physiological demands of players according to the specific position covered during the handball match.

Approximately 25–35% of total muscle glycogen stores are used during a resistance exercise. In handball, some of the specific positions, for example, wings, have been shown to be characterized by a high frequency of sprints as well as by covering greater distances, a fact that is probably related to their position on the playing field [9]. These types of metabolic pathways will also be fundamental during a handball match in specific positions such as backcourt and pivot players, where it has been observed that there is a large number of actions required over longer periods of time with intensities of approximately 80% of the maximum heart rate [13]. The oxidative

Table 7.1 Physical and physiological demand quantification according to specific positions in handball players [10]

Position	Technical demands			Motor analysis				High intensity actions		Physiological load		
	Shoot	Pass	Contacts	Running pace	Low intensity movements	Moderate intensity movements	High intensity movements	Sprints	Total	Low	Moderate	High
Back	****	****	***	***	**	****	***	***	***	*	****	***
Pivot	**	*	****	**	***	**	**	**	***	*	**	****
Wing	**	***	**	***	**	*	***	****	*	**	***	**
Goalkeeper				*	****	**	*			***	**	*

The magnitude of playing position demands with respect to technical activities, distance covered, high-intensity actions, and physiological load variables is rated from low (*) to very high (****)

route will be an alternative route in events taking place longer than 2–3 min taking into account that both phosphagen and glycolytic cannot sustain the rapid supply of energy to allow muscles to contract at a very high rate for those longer events. The main substrates include glycogen in the muscle, liver, blood, and triglycerides in adipose tissue, as well as small amounts of amino acids in the muscle, blood, liver, and intestines [12].

Taking the physiological demands into account, the energy and macronutrient intake guidelines in a handball player's diet should therefore be based on a fundamental understanding of how the interactions between competition and nutrients affect energy systems, substrate availability, and training adaptations. While specific physiological demands may vary between team sports (e.g., game frequency, season length, specific position requirements), a common feature is the nature of team sports, with "bursts" of high intensity interspersed with periods of less intense activity or with rest periods. In handball, the energy demands will be related to the position as well as individual offensive and defensive situations in the game [13, 14].

7.4 Size and Body Composition in Handball Players

The association between morphology and performance has been considered in many contexts in sports. In fact, the study of body size remains a very active area of research in sports sciences and particularly in throwing events like handball. Handball is a physically demanding sports in which strength, power, and physical contact are critical elements for success. Current studies describing the physical characteristics of elite male and female handball players are outlined in Table 7.2.

In team sports like handball, players are characterized as strength-and-power athletes. Athletes are usually large and muscular. However, depending on the specific position, body composition varies slightly. In reality, wings are smaller players and carry little body fat, while pivots and backs tend to be tall and powerful (reviewed in [15]). Likewise, the high number of explosive actions as well as one-on-one actions with contact will make the muscular component and its control throughout the season a key to good sports performance [9, 10]. In addition, it seems that, to be successful in a specific sport, it is important to have specific body attributes. In fact, body mass can influence the speed, endurance, and power of an athlete, while body composition may affect an athlete's strength and agility [16]. It is also well established that successful players should be tall with high amounts of fat-free mass and a high level of anaerobic power [17].

Data from Gorostiaga et al. [18] describing the physical attributes of handball players found that this elite athletes were heavier and had a higher fat-free mass than amateurs and concluded that this seems to be advantageous in handball. Similarly, results from Bon et al. [19] found that female handball players who participated in a higher level of competition tended to be taller, leaner, and heavier, and their group was homogenous in somatotype characteristics.

Certain anthropometric characteristics have a significant influence on position-related performance in sports [20, 21]. Regarding the specific position profiles, the comparative results in Table 7.2 show that on average the wings differ the most from the other player groups in terms of their morphological body characteristics. Values for body height and body mass and the quantity of subcutaneous fat were lower in wings than in players in the other groups. This may be explained by the role of wings, who are required to rapidly shuttle from defense to offense and

Table 7.2 Anthropometrical characteristics in male and female handball players

Study	Sample	Anthropometrical measurements	Level of performance			
			Top-elite	Moderate-elite	Sub-elite	Junior-elite
Massuça et al. [16]	*n* = 212 male handball players: Top-elite, moderate-elite, sub-elite and junior-elite.	Height	Height (cm)			
		Skinfolds body mass and fat free mass indirect predicted	187.2 ± 5.2	182.1 ± 6.5	179.8 ± 6.2	179.5 ± 15.5
			Body fat (%)			
			10.5 ± 5.4	12.6 ± 5.2	13.0 ± 5.5	10.8 ± 5.6
	Age = 23 ± 5 years		Fat free mass (kg)			
			51.9 ± 4.9	48.4 ± 6.4	47.0 ± 4.9	46.1 ± 8.3
			Elite		**Amateur**	
Gorostiaga et al. [18]	*n* = 15 elite male team.	Height	Height (cm)			
	Age: 31 ± 3 years.	BMI	188.7 ± 8.0		183.9 ± 7.0	
	n = 15 amateur male team	Body mass and and fat free mass	Body mass (kg)			
	Age: 22 ± 4 years.		95.2 ± 13.0		82.4 ± 10.0	
			Body fat (%)			
			13.8 ± 2.0		11.6 ± 3.0	
			Fat free mass (kg)			
			81.7 ± 9.1		72.4 ± 7.0	
Study	Sample	Anthropometrical measurements	Specific positions			
			Goalkeepers	**Backs**	**Wings**	**Pivots**
Nikolaidis et al. [67]	*n* = 39 adult male players in the first league.	Height	Height (m)	Height:	Height:	Height:
		BMI	1.88 ± 0.1	1.87 ± 0.1	1.78 ± 0.1	1.86 ± 0.1
	Age: 26.6 ± 5.7 years	Skinfolds BM and FFM indirect predicted	BMI (kg/m^2)	BMI:	BMI:	BMI:
			25.1 ± 1.8	25.1 ± 2.9	24.3 ± 1.9	27.1 ± 1.3
		Health-Carter for somatotype	Body fat (%)	BF:	BF:	BF:
			18.6 ± 4.0	18.8 ± 4.2	15.3 ± 3.0	19.5 ± 2.4
			Fat free mass (kg)	FFM:	FFM:	FFM:
			72.0 ± 4.2	72.0 ± 4.2	72.0 ± 4.2	72.0 ± 4.2
			Somatotype			
			Endomorph:	Endo:	Endo:	Endo:
			3.9 ± 1.1	4.1 ± 1.4	3.1 ± 0.9	3.9 ± 0.7
			Mesomorph:	Meso:	Meso:	Meso:
			4.9 ± 0.6	5.1 ± 1.6	5.5 ± 1.0	5.9 ± 0.8
			Ectomorph:	Ecto:	Ecto:	Ecto:

Table 7.2 (continued)

Study	Sample	Anthropometrical measurements	Level of performance Top-elite	Moderate-elite	Sub-elite	Junior-elite
			2.3 ± 0.9	2.2 ± 1.3	2.1 ± 1.0	1.5 ± 0.5
Ghobadi et al. [21]	*n* = 409 handball players form 24 teams in the 2013 World Men's Handball Championship	Height	Height (cm)	Height:	Height:	Height:
		Body mass	191.8 ± 5.1	192.6 ± 6.6	185.1 ± 5.4	192.6 ± 6.3
		BMI	Body mass (kg)	Body mass:	Body mass:	Body mass:
			95.6 ± 10.4	94.1 ± 8.2	84.6 ± 6.4	99.6 ± 9.4
			BMI (kg/m^2)	BMI:	BMI:	BMI:
			25.9 ± 2.8	25.3 ± 1.7	24.7 ± 1.4	26.8 ± 2.1
Milanese et al. [22]	*n* = 43 adult female elite and sub-elite players in the Italian national championships	Height	Height (cm)	Height:	Height:	Height:
		BMI	169.3 ± 7.4	171.0 ± 5.8	165.2 ± 4.4	167.0 ± 4.3
		Skinfolds and body circumferences	BMI (kg/m^2)	BMI:	BMI:	BMI:
		Total body and regional composition (lean mass, fat mass, and mineral mass) with DXA	25.9 ± 2.2	23.1 ± 1.7	22.3 ± 2.1	23.9 ± 1.4
			Body fat (%)	BF:	BF:	BF:
			29.7 ± 4.5	25.1 ± 5.5	24.4 ± 5.0	22.7 ± 6.2
			Fat free mass (kg)	FFM:	FFM:	FFM:
			48.8 ± 5.3	47.4 ± 4.8	43.2 ± 4.7	48.3 ± 6.2
Sibila et al. [20]	*n* = 78 handball players members of the Slovenian junior and senior national.	Height	Height (cm)	Height:	Height:	Height:
		BMI	187.9	191.1	183.6	188.6
		Skinfolds, diameters and body circumferences	Body mass (kg)	BM:	BM:	BM:
	Age = 25.1 ± 4.3 years		89.9	91.5	83.8	92.2
			Body fat (%)	BF:	BF:	BF:
			12.5	11.4	10.0	11.6
			Fat free mass (kg)	FFM:	FFM:	FFM:
			45.4	47.7	44.3	47.8
			Somatotype			
			Endomorph:	ENDO:	ENDO:	ENDO:
			3.65	2.97	2.62	3.06
			Mesomorph:	MESO:	MESO:	MESO:
			4.75	4.61	5.06	5.34
			Ectomorph:	ECTO:	ECTO:	ECTO:
			2.17	2.50	2.16	1.99

often throw at the goal without significant contact with the rival defensive players, attempting to exploit speed and agility [22]. Goalkeepers are relatively tall, with high body mass values; the same is true for pivots. Consequently, the endomorphic component of the somatotype was more pronounced in the abovementioned positions. Pivot and back players are becoming increasingly similar in terms of their morphological body characteristics.

The measurement of anthropometric characteristics provides an insight into the current status of handball players, allowing coaches and sports dietitians to evaluate typical characteristics of elite athletes. In general, handball players occupying different positions differ among themselves in terms of anthropometry. This information should serve as a reference with the purpose of establishing the specific requirements of handball players which could lead to the design of more specific nutritional strategies to maintain their body composition throughout the precompetitive and competitive season.

7.5 Energy Assessment in Handball

Optimum energy intake is the key to the athlete's diet, determined by the intake of macronutrients and micronutrients in order to support optimal physiological functions and body weight in response to the continuous physical demands arising from exercise. In general, an athlete's energy intake comes from the consumption of foods, liquids, and supplements that can be recorded using different methods including retrospective food intake questionnaires (24 h, 48 h, 72 h, or 7 days) or food frequency questionnaires [23]. An athlete's energy needs in team sports will depend on the training and competition cycle, duration, and frequency of matches, length of the season (during the preseason training phase, sessions are usually held twice a day, and physical exertion is very high), training phase, and number of players and substitutions [15].

Energy balance, therefore, occurs when energy consumption is equal to total energy expenditure (TEE) or the sum of the energy expended as the basal metabolic rate (BMR), the thermal effect of the food, the thermal effect of the activity (energy expended on planned physical activity), and thermogenesis of resting activity. Spontaneous physical activity is also included in the TEE [24]. Handball players need to consume enough energy to maintain a proper body weight and body composition while practicing this sports [9, 22]. The selection of handball players for each game position is based on morphological characteristics to perform the required tasks with the highest efficiency [11, 20, 25]. The tallest players should thus be assigned to back player positions. With regard to pivots, besides body height, coaches must also consider robustness. For goalkeepers, body height is very important, while the robustness criteria are slightly lower. For wings, body height is not a decisive factor, and smaller players can also occupy this position [10].

On the field, an accessible and practical way to assess the daily energy expenditure of an athlete is to use prediction equations based on assessments of resting metabolic rate and the energy expenditure for daily activities like the Cunningham [26] and Harris-Benedict equations [27]. These equations have allowed for the calculation of TEE, taking into account the BMR multiplied by activity factor 1.8 (moderate physical activity) or 2.3 (vigorous physical activity). Nevertheless, the categorization of the activity factor could imply an error that will cause us to over- or underestimate the total energy expenditure of a handball player. Likewise, TEE estimation by metabolic equivalents (METs) can be used as another tool for a sports dietitian in order to determine energy consumption requirements, allowing them to guide active athletes or active individuals to meet their energy needs [28]. The quantification of TEE by METs is widely extended in research, although the trend is changing to more precise methodologies in search of more precise values in the estimation of TEE.

Based on the aforementioned methodology, the estimated TEE in handball players at the beginning of and during the sports season has been around 2700–3200 kcal/d and 3100–3600 kcal/d, respectively, for males [29] and 1800–2400 kcal/d for women [7, 30]. TEE estimation in handball players provides an approximation of the average energy needs of an individual athlete by analyzing a total of 553 athletes from different sports disciplines, finding small differences in mean energy and macronutrient intake among team sports athletes [30]. Throughout the studies analyzed, no TEE classification was observed regarding the different specific positions of handball players. However, Michalsik et al. [11, 14, 25] provide additional information about the physical demands classified by specific positions in male and female handball players which could allow for a more accurate calculation of the TEE considering the time, the duration, and the frequency of the different actions during training or competition.

A recently published study by Silva et al. [31] accurately measured the TEE with the doubly labeled water (DLW) method. The validity of the

DLW in assessing TEE has a coefficient of variation between 3% and 5% [32]. In this sense, the TEE was estimated in 80 athletes from different sports disciplines where male handball players showed a TEE of 3603 ± 714 kcal/d and 4188 ± 666 kcal/d at the beginning of the season and during a competitive period, respectively. This would open a new discussion since the results of the present study might suggest that the TEE has been previously underestimated in these athletes and, therefore, more research would be needed to clarify these results. It was also observed that the transition from a precompetitive period to the competitive period meant an increase of 586 ± 401 kcal/d, similar to what was reported by Molina et al. [29]. It is important to mention that it would be essential to be able to classify energy expenditure according to the position of each player since, as we have observed, the intensity and volume of actions in a handball game will be very different according to the positions of the players [16].

Although the usual energy intake per kilogram of body weight for many athletes undergoing intense training is adjusted to the energy requirements, some athletes could not cover their TEE. It has often been reported that inadequate intake may compromise athletic performance [1], so the work of the sports nutritionist plays a key role in the athlete's nutritional status by developing appropriate and individualized intervention strategies. In handball [29, 33, 34], Molina et al. observed an insufficient intake of energy and macronutrients in elite handball players. These players underwent a nutrition education program to improve the quantity and quality of nutrient intake, observing improvement after the intervention, yet they failed to present a correct balance between the energy consumed and the energy intake recorded by a retrospective 72-h questionnaire. With limited energy intake, fat and lean tissue will be used as substrates in obtaining energy. A diet deficient in energy may result in the loss of muscle mass, strength, and endurance, as well as impaired immune, endocrine, and musculoskeletal function [35], which may lead to menstrual dysfunction; increased loss or lack of bone density; increased risk of suffering fatigue, injury, and illness; and an extended recovery process. Athletes need to consume adequate energy during periods of high-intensity and/or long-term training to maintain body weight and health and to maximize the effects of training [1, 2]. In reference to the energy balance, Silva et al. [31] measured the difference between the TEE and the energy intake with the DLW methodology. They assume that changes in physical activity energy expenditure due to exercise training demands should theoretically change the balance between energy intake and energy expenditure. For this reason, they estimate the energy balance taking into account the changes in fat mass and fat-free mass in response to exercise. The follow-up study over one season ranging from 5 to 10 months showed a positive energy balance in handball players, concluding that they had a proper energy intake according to the TEE they presented (TEE 3603 ± 714 kcal/d and 4188 ± 666 kcal/d at beginning of season and during a competitive period). As a result, an increase in fat-free mass content was described for handball athletes compared to other team sports.

7.6 Macronutrient Status in Handball

The contribution of macronutrients in athlete nutrition plays a fundamental role in promoting benefits associated with their balance and adequacy in intake. These adequacies will be defined by the intake of elements, for example, carbohydrates, proteins, and lipids, present in all foods that are part of a healthy and balanced diet. Nonetheless, it is important to know how to choose them according to our body's specific needs. That is, an athlete belonging to an endurance discipline will not consume the same source or the same amount of energy as an athlete who belongs to a strength discipline. There are already diverse studies and organizations including the International Society of Sports Nutrition (ISSN) and the ACSM that provide macronutrient guidelines to promote optimal health and sports performance across different training and competitive sports scenarios [1, 2, 36–39].

7.6.1 Carbohydrate Requirements

Carbohydrates (CHO) have received special attention in sports nutrition because of their importance for training and competition intensity. CHO serve as the main substrate to form part of the anaerobic and oxidative pathways, providing key fuel for the brain and central nervous system and a versatile substrate for muscle work. In addition, when working with the higher intensities that can be supported by oxidative phosphorylation, CHO will provide a higher yield of ATP per volume of oxygen that can be delivered to mitochondria, thereby optimizing exercise efficiency [40]. CHO are a limited fuel, so paying special attention to daily dietary intake through a controlled suitable diet is required (Fig. 7.2).

Handball requires a high number of high-intensity actions, which in a large part trigger anaerobic glycolysis [10]. Some authors have classified handball within the field games that combine strength and power with endurance [15]. In general, the CHO intake in handball athletes was observed within a range of 48–51% of the total energy intake (Fig. 7.3), which is below some previous recommendations (55–65%) [2]. According to different authors, in relation to body mass, male handball players reported ingesting an average of 4.1–4.8 g/kg/d CHO [33], while female players consumed about 3.7–4.0 g/kg/d CHO, again falling below the recommendations proposed by the ASCM or ISSN for CHO intake (6–10 g/kg/d) [1, 2]. Comparing these results with those obtained by Holway et al. [15] in a systematic review in team sports, we notice that, in general, CHO intake was also around 49% of energy intake, although higher values for CHO relative to body mass were reported in males (5.6 ± 1.3 g/kg/d) and females (4.0 ± 0.7 g/kg/d). In addition, CHO requirements on match days tend to be higher than those on weekly training days due to altering the normal eating pattern as a result of game stress [35].

It is important to mention that the handball match's impact on other physical capacities important for performance such as the ability to sustain a high average intensity during a long period of time or to perform short-duration high-intensity exercise and possible alterations in these performance indices after certain intense periods of the match remains unknown [13]. In this way, the role of CHO would become even more important in order for players to be able to tolerate the same intensity during the two periods of a handball match. In 2015, Russel et al. [42]

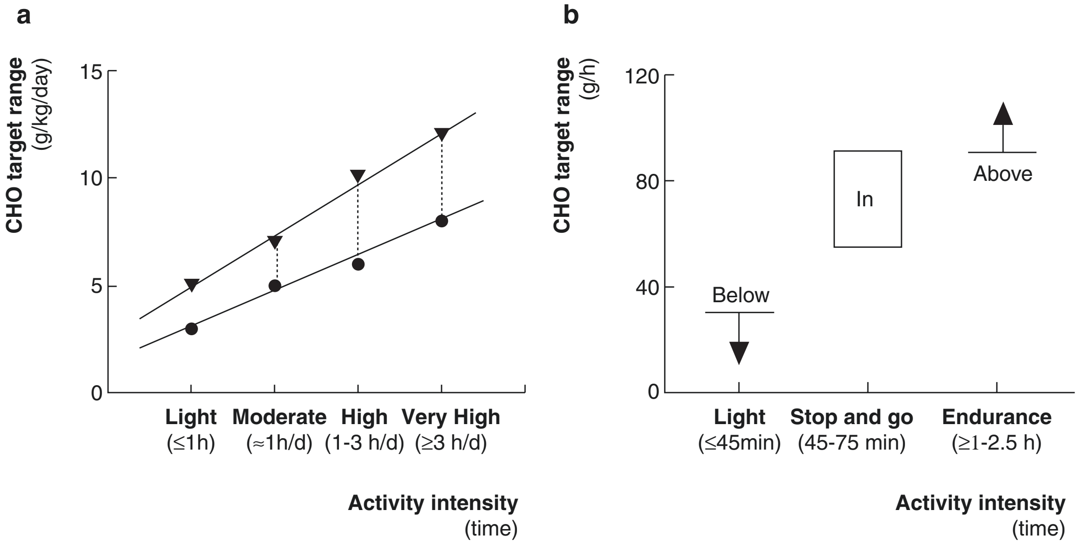

Fig. 7.2 Summary of guidelines for carbohydrate intake by athletes. Adapted from [41]

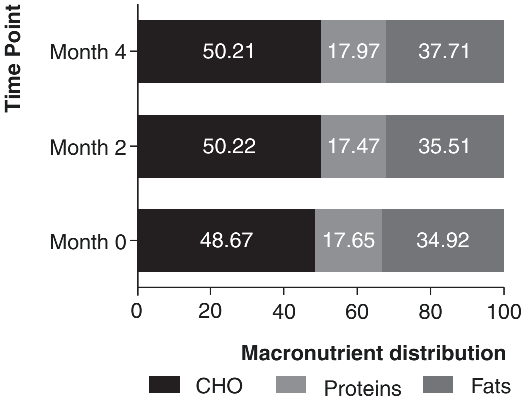

Fig. 7.3 Percentage of macronutrient intake referred to total energy intake at three time points during the first phase of a top handball league. Adapted from [29]

published a paper in *Sports Medicine* revising and giving recommendations about half-time strategies to enhance second-half performance in team sports players. From a nutritional perspective, this author emphasized the importance of nutritional strategies including rehydration and refueling strategies, attenuating the reduction in exercise performance, and increasing the glucose uptake by the previously active muscles. Given the pattern of competitive match play in a handball competition, more research is needed in order to evaluate the influence of carbohydrate supplementation on the glycemic response in those conditions.

7.6.2 Protein Requirements

Protein is an important nutrient in an athlete's diet, providing a trigger and a substrate for the synthesis of contractile and metabolic proteins, as well as improving structural changes in non-muscle tissues like tendons and bones, in addition to recovery after training sessions [36, 43]. Therefore, protein intake may be a priority in the diet of a handball player because players differ in weight, height, fat percentage, and muscle mass according to specific positions, with backs and pivots presenting higher body weight, muscle mass, and height, while the wings tend to have a lower stature and lower muscle volume [9, 16, 44].

Protein recommendations in athletes have been described by the ACSM and ISSN organizations [1, 2]. Current data suggests that the dietary protein intake required to support metabolic adaptation, repair, remodeling, and renewing proteins generally ranges from 1.2 to 2.0 g/kg/d [1]. In particular, recommendations in athletes will be classified according to the type of exercise. In endurance disciplines, the reference recommendation range should be 1.2–1.4 g/kg/d, while higher quantities will be associated with strength disciplines (1.4–2.0 g/kg/d) [43, 45, 46].

Handball players have described a protein intake within the abovementioned recommendations for strength-power disciplines. Male handball athletes were observed to generally consume an average protein intake between 1.5 and 1.7 g/kg/d, representing 17% of the total energy intake (Fig. 7.3). Similar results in other team sports such as volleyball, basketball, and hockey showed protein intakes ranging between 1.2 and 2.0 g/kg/d [30]. With regard to the contribution of macronutrients to the total energy intake, Wardenaar et al. [30] observed that the contribution of protein to the total energy was higher (17.8%) in female compared to male (16.1%) team sports athletes. Finally, in a systematic review published by Holway et al. [15], the mean daily protein intake reported was around 1.2 and 1.8 g/kg/d for male and female athletes, respectively. In general, it is evident that most team sports athletes, including women, consume adequate protein (>1.2 g/kg/d) to meet daily recommendations [47]. Future research will further refine recommendations aimed at total daily amounts, time strategies, and quality in protein intake providing new recommendations for protein supplements derived from various protein sources.

7.6.3 Fat Status

Fat is a necessary component of a healthy diet which provides energy and essential elements of cell membranes and facilitates the absorption of fat-soluble vitamins including vitamins A, D, and E. Fat is also an important fuel for aerobic exercise. However, at a given exercise intensity and metabolic demand, there can be reciprocal shifts in the proportions of CHO and fat that are oxidized [40]. The ACSM has estimated a range between 20% and 35% of the total energy intake for fats in athletes [48].

Handball players often consume high-fat diets reaching around 40 percent of the total energy intake (Fig. 7.3) [29]. This represents an average of 1.3–1.5 g/kg/d above the fat recommendations of 0.9–1.1 g/kg/d [2]. Certainly, the type of fat in the diet is a factor in the research and could play an important role in any discrepancy [49, 50]. In addition, the balance of essential fatty acids is often unbalanced, always exceeding the consumption of saturated fats (Fig. 7.4). In other team sports, fat intake has been estimated at a range from 24 to 42% of total energy intake recorded by 3-day dietary intake questionnaires (reviewed in [15]). On the other hand, a relatively lower fat intake was observed in female athletes compared to male athletes, between 23% and 29% of the total calories ingested [47]. It is important to mention that athletes should be discouraged from the chronic implementation of fat intake below 20% of energy intake. The reduction in dietary variety often associated with such restrictions is likely to reduce the intake of a variety of nutrients like fat-soluble vitamins and essential fatty acids [48].

Fat is present in the body as plasma-free fatty acids in the blood, intramuscular triglycerides, and adipose tissue and provides a fuel substrate that is relatively abundant, increasing the availability in muscle as a result of endurance training. Some studies [51] have suggested that a high-fat diet could increase the amount of oxidized fat during exercise. Conversely, it could also reduce muscular training adaptations, compromising the exercise performance. It is important to note that certain deficiencies may be promoted for several micronutrients as a consequence of a homogeneous diet, mainly due to an imbalance in macronutrients. Therefore, studies that suggest a positive effect of dietary intake for which fat provides above 70% of energy intake in athletic performance should be carefully evaluated [52].

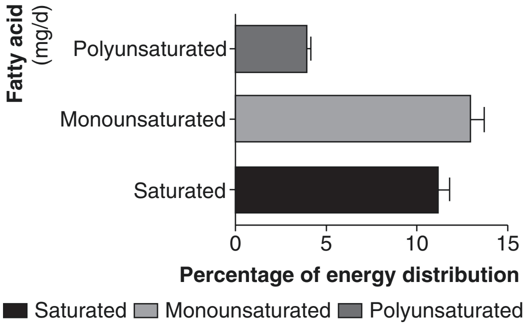

Fig. 7.4 Percentage of fatty acid intake compared to total energy intake in handball players. Adapted from [29]

As for the type of fat ingested, we must pay special attention to the type of fat that we assimilate through the diet. The Interim Summary of Conclusions and Dietary Recommendations on Total Fat & Fatty Acids from the Joint FAO/WHO Expert Consultation on Fats and Fatty Acids in Human Nutrition, November 10–14, 2008, WHO, Geneva [53], makes recommendations that the proportion of energy from fatty acids be <10% saturated, 6–11% polyunsaturated, and 10% monounsaturated (the resulting monounsaturated fatty acid intake may cover a wide range depending on the total fat intake). Taking these recommendations into account, handball players generally present an unbalanced intake of fatty acids, showing an excess for saturated fatty acids and a slightly insufficient intake of polyunsaturated fatty acids [29].

7.7 Micronutrient Status in Handball

Micronutrients play an important role in energy production, hemoglobin synthesis, maintenance of bone health, adequate immune function, and protection of the body against oxidative damage [2]. Notably, they assist in many metabolic pathways where micronutrients are required, and exercise training may result in biochemical muscle adaptations, synthesis and repair of muscle tissue during recovery from exercise, and a decrease in oxidative stress promoted by exercise. As a result, greater intakes of micronutrients may be required to cover increased needs for the building, repair, and maintenance of lean body mass in athletes [54].

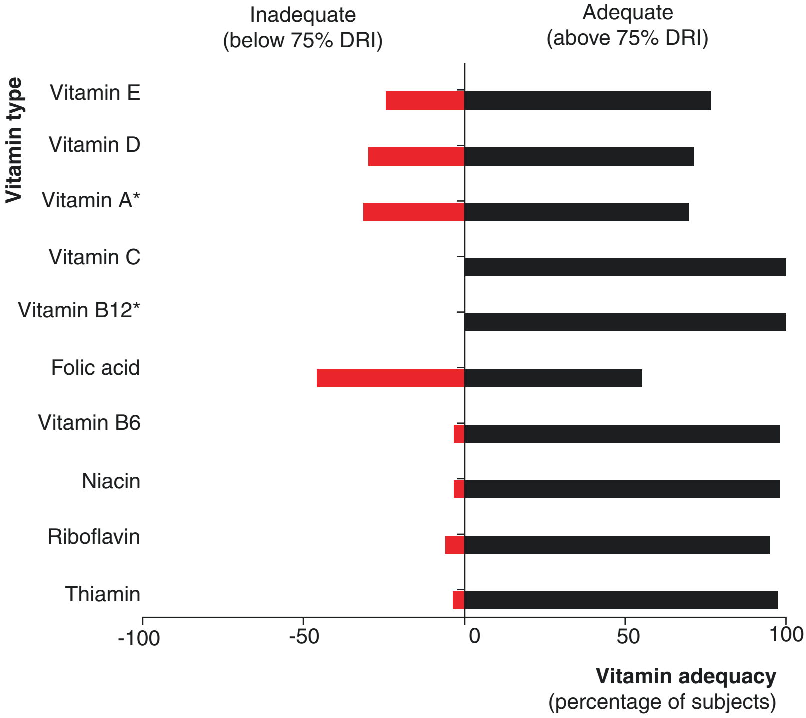

Fig. 7.5 Percentage of vitamin adequacy in handball players in accordance with the European and Spanish dietary reference intakes. Adapted from [29]. Vitamin intake is expressed as mg/d; * Vitamin intake expressed as µg/d, *DRI* dietary reference intake

The micronutrients that have to be considered are those which might be insufficiently ingested (Fig. 7.5) and those which may be lost in excess during physical exercise. Another reason to consider these micronutrients is linked to the assumption that training induces a biochemical adaptive response which might require an increase in the ingestion and/or the absorption of vitamins. Consequently, several authors have put forward the hypothesis that for some athletes, intake of certain antioxidant micronutrients might be less than they actually need.

7.7.1 B Vitamins Adequacy

Adequate intake of B vitamins is important to ensure optimum energy production and the construction and repair of muscle tissue [55]. B vitamins have two main functions which are directly related to exercise. Thiamine, riboflavin, niacin, pyridoxine (B6), pantothenic acid, and biotin are involved in energy production during exercise [56, 57], while folate and vitamin B12 are necessary in the production of red blood cells and the repair and maintenance of tissues including the central nervous system. There have been limited studies examining whether exercise increases the need for B complex vitamins in handball players. Be that as it may, a recent study analyzed the role of B vitamins at the cardiovascular level [33]. It was concluded that folic acid supplementation could protect athletes from alterations that may lead to cardiovascular events related to exercise during training and competition. It is known that both low folic acid intake and moderate exercise are major contributors to increased homocysteine (Fig. 7.6) [58, 59]. Elevated levels of homocysteine in the blood (hyperhomocysteinemia) are associated with cardiovascular disease as a result of its interrelationship with methionine metabolism [58, 60].

An inadequate intake of folic acid has been described more frequently in athletes who practice different sports [47, 55], mainly promoted by the insufficient intake of total calories, carbohydrates, proteins, and other micronutrients [61]. Although short-term marginal deficiencies of B

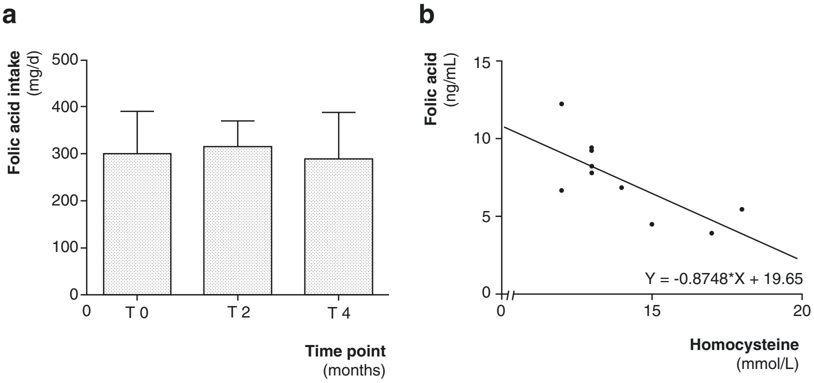

Fig. 7.6 (**a**) Folic acid intake at three time points during the first phase of a top handball league. (**b**) Relationship between plasma folic acid and homocysteine in handball players. Adapted from [29]

vitamins have not been observed to affect performance, a severe deficiency of vitamin B12, folic acid, or both may result in anemia and decreased endurance performance [2, 62]. Therefore, it is important to consume adequate amounts of these micronutrients in order to support their efforts for optimum performance and health. Current research suggests that exercise may increase riboflavin and vitamin B6 requirements. In any case, more research is needed to determine whether exercise increases the need for folate and vitamin B12 [55].

7.7.2 Antioxidant Vitamins

Antioxidant vitamins are necessary to allow endogenous adaptation and to avoid excessive stress. This could induce various forms of cellular damage, the alteration of cellular functions, and, in the case of excessive stress, cellular death by apoptosis, necrosis, and muscular adaptations [63]. Based on this, antioxidant nutrient requirements have created growing interest during the past decade. To date, exercise-induced oxidative stress brings up the question of the optimal conditions for the adaptation of antioxidants [64]. The question of dietary recommendations for antioxidants in athletes has yet to be addressed.

In handball players, the intake of vitamin C was not shown to be insufficient (Fig. 7.5) [29]. The optimal bioavailability of vitamin C is shown to be reached with an intake of 200 mg/d [63]. As a consequence, any supplement above this intake threshold has no effect on vitamin C plasma concentrations [65]. Basal ascorbic acid concentrations in plasma in some athletes may be below the reference range and in some cases reach marginal concentrations. These athletes are mainly those involved in team sports or those who followed periods of intensive training (reviewed in [64]). Hypothetically, the decrease in vitamin C, along with other antioxidants [66] in the early days of recovery from strenuous or prolonged exercise, particularly if muscle damage and inflammatory responses were induced, may be associated with an increased utilization of vitamin C due to sustained oxidative stress in the blood [67]. On the contrary, it should be noted that the consumption of supplements can generate prooxidant effects when the intake is above 500 mg/d [68].

In contrast, vitamins A and E were below the DRIs for the Spanish and European Union population intakes in a follow-up in handball players [29], a finding also reported by Iglesias-Gutiérrez et al. [69] in their study on Spanish team sports athletes. Recent research suggests that athletes generally tend to consume enough food to have an adequate intake of most micronutrients with some exceptions for vitamins A and E in specific athletic groups [70]. Although in most cases vitamin E intake among well-trained athletes is below 12 mg/d, the recommendation for the general population, this population does not present the risk of having a marginal status [71]. One has to be cautious when interpreting plasma vitamin E concentrations during training periods. Indeed, the higher the training intensity is, the higher plasma vitamin E concentrations are [72].

Moreover, within a short recovery period, plasma concentrations of vitamin E may still remain high. Consequently, the variation in training loads should be taken into account when interpreting vitamin E status (reviewed in [64]). Although the ergogenic potential of vitamin E in terms of physical performance has not been clearly documented, endurance athletes may have a greater requirement. Supplementation with vitamin E did not attenuate the oxidative stress in skeletal muscle or the gene expression of mitochondrial biogenesis markers following acute exercise, but supplementation attenuated some of the increased skeletal muscle adaptation after competition in healthy young men [73].

With regard to vitamin A intake, it has generally been found to be adequate in elite athletes, although it has been reported that 10–25% of athletes studied consume less vitamin A than dietary reference intakes [29]. Interestingly, serum vitamin A levels in 5% of the 182 athletes studied had a value below 30 mg/dL (reviewed in [74]). There has been no evidence of serious biochemical deficiencies of vitamin A in athletes. It has been observed that the decrease in vitamin A was directly related to an increase in oxidative stress in athletes with a low VO2max, while athletes with a moderate VO2max better supported oxidative stress promoted by exercise [75] and a reduction of lipid peroxidation [54].

Vitamins have also been widely studied to help athletes reduce oxidative damage, maintain a healthy immune system [76], and play a beneficial role in injury prevention and tissue repair in response to exercise [77, 78]. Theoretically, this can help athletes tolerate competition while leading to improvements in performance. Because exercise can increase oxygen consumption by 10–15 times, it has been hypothesized that long-term exercise produces constant "oxidative stress" in muscles and other cells [79], leading to lipid peroxidation of the membranes. Regardless, the requirements of antioxidant micronutrients and antioxidant compounds for athletes have not been sufficiently determined (reviewed in [63]).

In reference to vitamin C supplementation, Bonina et al. [80] evaluated the effects of short-term dietary supplementation with antioxidants on oxidative stress in a group of professional handball players. Their results clearly reflect an overall lower level of oxidative stress in the athletes examined after short-term dietary supplementation. However, the initial status of the antioxidant vitamins was not determined, and some methodological considerations were not taken into account in order to attribute the improvement of the antioxidant system in the athletes as a consequence of supplementation rather than as a response to the exercise. It is clearly demonstrated that oxidative stress, biochemical parameters, and antioxidant enzymatic defense can be modified by the training load in team sports like handball [81]. In fact, the increase in oxidative stress blood levels throughout the training season occurred despite the possible upregulation of antioxidant systems. Future studies in handball athletes should investigate whether this oxidative stress is detrimental to exercise performance and the potential role of antioxidant supplementation.

Supplementation with antioxidants appears to be useful in cases of insufficient intake of those vitamins, although no performance benefits were shown in athletes with adequate intakes and excess supplementation could reach harmful levels [64]. In addition, it should be noted that under certain circumstances, these antioxidants may be converted into prooxidative agents. The assumption of increased need in relation to antioxidant vitamins remains controversial. Although there are no specific recommendations for athletes, it seems that need is increased by exercise. In accordance with that, several authors try to determine how exercise increases micronutrient needs [54, 55, 63, 64]. Nevertheless, the variety of sports disciplines makes determining a universal requirement for all sports difficult. Supplementation is recommended in case of a diagnosed deficiency, although this rarely occurs in healthy endurance athletes who eat a balanced diet.

7.7.3 Vitamin D

Several authors [82] have demonstrated vitamin D deficiency in handball players among other team sports studied and its relationship with cardiac structure and function. From 506 athletes, a total of 30% of subjects presented vitamin D insufficiency (20–30 ng/mL), 37.2% deficiency (10–20 ng/mL), and 11% severe deficiency (<10 ng/mL). In this study, the vitamin D-deficient subjects presented significantly smaller cardiac structural parameters than insufficient and sufficient athletes and, consequently, significantly smaller cardiac structural parameters. Similarly, Molina et al. [29] presented an insufficient intake in elite male handball players which may make us think that these athletes could be a vulnerable group for this vitamin.

The data concerning vitamin D status in athletes is far from complete, but the available literature reveals vitamin D deficiency among athletes within the range of 42–83% [83]. Despite the limitations of the current evidence, the prevalence of vitamin D inadequacy in athletes is prominent. Moreover, regular investigation of vitamin D status using reliable assays and supplementation is essential to ensure healthy athletes. The prevalence of injuries in athletes is notable, but its association with vitamin D status is unclear. A well-designed longitudinal study is needed to confirm this possible association. One study evaluated the seasonal vitamin D status in 409 elite athletes (indoor vs. outdoor) according to sun exposure and oral supplementation [84]. With the exception of a few summer months, an inadequate vitamin D status was found in the majority of elite athletes, and the most serious deficiency was observed in indoor disciplines. Athletes should therefore routinely assess their vitamin D status and be educated about how to approach their sunlight exposure, diet, and supplementation.

7.7.4 Minerals

Minerals are required in small amounts and interact with each other to regulate physiological functions [1, 2]. Minerals such as iodine, iron, magnesium, and zinc are extremely important in enhancing the conversion of macronutrients into energy and are essential for athletes due to their high levels of energy expenditure [54, 58]. In particular, the production of red blood cells is usually increased in athletes, so additional iron intake is required to take part as a component of hemoglobin, also necessary for DNA and RNA synthesis [64]. As well as iron, adequate levels of calcium, phosphorus, and magnesium ensure the maintenance of bone mineral density, helping to prevent stress fractures (reviewed in [1]). Certain minerals like selenium and zinc protect cells and tissues against damage by oxygen free radicals, which are increased by exercise (reviewed in [2]). Although athletes may have slightly higher mineral requirements because exercise emphasizes many of the metabolic pathways in which micronutrients are involved, no special recommendations have been defined. To date, there are no specific mineral recommendations for athletes, although the scientific literature has described that micronutrient requirements are generally increased with exercise. Both the ACSM and the ISSN recommend a well-balanced diet to meet mineral requirements [1, 2]. However, athletes with limited energy intake are at increased risk of inadequate mineral intake.

Until now, very few studies examined the status of minerals among handball players, and most of these studies have reported low intake levels. One study carried out in professional handball players [29] reported a higher mineral intake than the recommendations for the healthy population (Fig. 7.7). In spite of this, it is important to note that, in general terms, the estimated total energy expenditure for these athletes was not covered. According to these results, an insufficient intake of minerals such as calcium, iodine, magnesium, and zinc has also been reported in both men and women in other team sports [47, 85]. In male handball players, normal magnesium and zinc status in blood was observed even though the athletes had an insufficient intake of magnesium [34]. Simultaneously, previous studies found that dietary intake did not cover 100% of dietary reference adequacy for Mg intake (400 mg/d). Nevertheless, a Zn intake above 100% of the dietary reference intake (11 mg/d) was found in the athlete population [62]. Because there are no specific recommendations for micronutrients in athletes, the requirements formulated for the general population may underestimate the real needs of high-performance athletes. As a nutritional strategy for mineral deficiency prevention, nutritional education has been carried out to promote an increase in energy consumption and, consequently, in the mineral density associated with the total energy intake.

A notable aspect of nutritional research in athletes is that most of the reviewed studies reported an alteration in Mg and Zn plasma and erythrocyte levels as a consequence of occasional compartmental redistribution promoted by exercise (Fig. 7.8) [34]. This fact could lead to confusion by believing that there is a mineral deficiency.

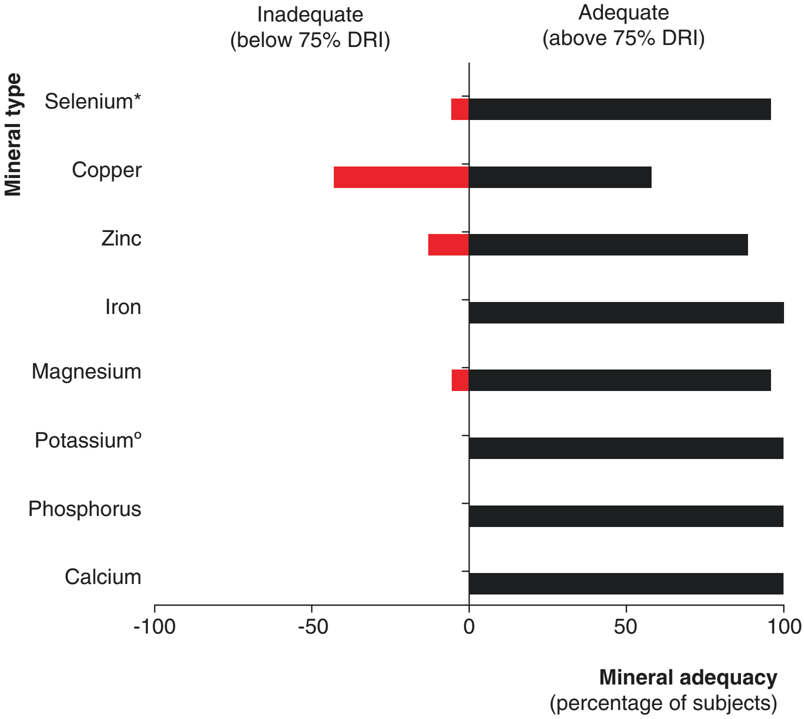

Fig. 7.7 Percentage of mineral adequacy in handball players in accordance with the European and Spanish dietary reference intakes. Adapted from [29]. Mineral intake is expressed as mg/d; * Mineral intake expressed as μg/d; ° Mineral intake expressed as g/d; *DRI* dietary reference intake

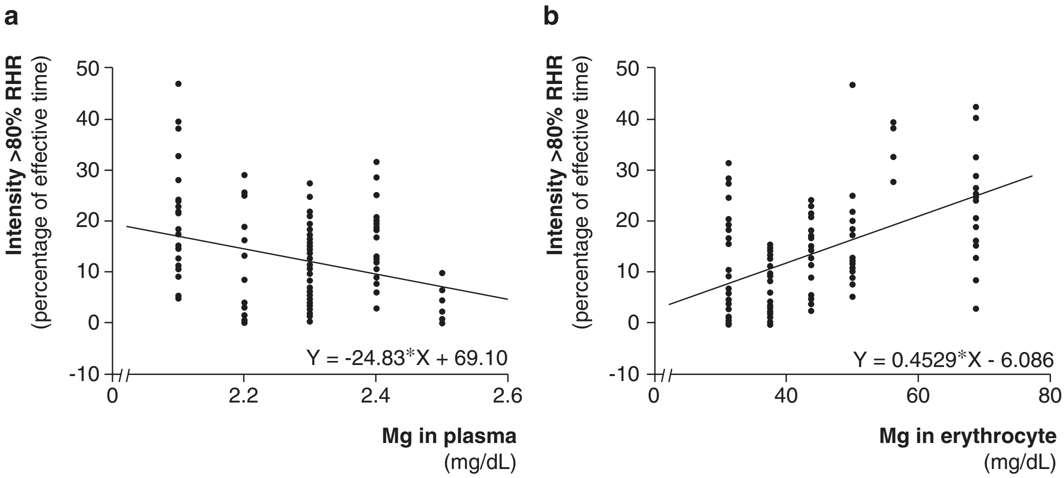

Fig. 7.8 Correlation between training volume in >80% of residual heart rate (RHR) intensity range and plasma and erythrocyte Mg concentrations in high-performance handball players. Adapted from [34]

However, this mobilization arises as a result of the mineral requirement demanded by tissue during exercise. Thus, it would be necessary to control the mineral status over a season in order to assess whether the deficiency is chronic and not sporadic. Previous studies without dietary supplementation found no change in plasma concentrations of any of the minerals in athletes after training [86]. In the same way, the relationship between magnesium status and strength in handball has been researched [87]. The regression analysis indicated that magnesium status in handball players was directly associated with maximal isometric trunk flexion, rotation and manual grip, jump tests, and isokinetic strength regardless of total energy intake. Therefore, the associations observed between magnesium intake and muscle strength performance may result from the important role of magnesium in energy metabolism, transmembrane transport, and contraction and relaxation of musculature.

On the other hand, female athletes appear to be the ones with the highest risk of low bone mineral density linked to low calcium intake. Current calcium recommendations for athletes with eating disorders, amenorrhea, and risk of early osteoporosis are 1500 mg/d of calcium and 400–800 IU/d of vitamin D (reviewed in [2]). Another of the minerals with a strong relationship with exercise is iron. Iron is necessary for the formation of oxygen-carrying proteins like hemoglobin and myoglobin and for enzymes involved in energy production, as well as oxygen-carrying capacity, the normal functioning of the nervous system, and the behavioral and immunological systems [76]. Iron deficiency, with or without anemia, can impair muscle function, limiting performance capacity. The likely influence of high training loads in team sports and contact-induced hemolysis make the specific needs of women greater, and there may be a higher incidence of iron deficiency. Relatively low concentrations of ferritin in athletes and the potential for further decline during the season when the physical load may be at its highest level, makes recommendable an hematological monitoring in combination with personal dietary advice [88]. We can conclude that annual evaluation may be beneficial for athletes with additional monitoring only when clinically indicated. Iron requirements for endurance athletes increase by approximately 70% of their recommendation of 18 and 8 mg per day for men and women, respectively (reviewed in [2]).

The intermittent nature of handball play makes it difficult to establish recommendations that will meet the athletes' actual requirements since this sports involves aerobic metabolism as the main energy source, alternating with periods of highly intense activity that require mainly anaerobic metabolism. To add to this challenge, optimum performance in handball requires a combination of physical attributes such as strength, power, speed, and endurance. An additional factor that needs to be considered is the lack of specific recommendations for micronutrient intakes in athletes.

7.8 Hydration

Being well hydrated is a key factor that contributes to optimal health and exercise performance. Daily fluid loss occurs from breathing, gastrointestinal and renal function, and sweating. Athletes need to replace sweat loss increased by exercise. Generated as a by-product of muscle work, sweating helps to dissipate heat. It is often exacerbated by environmental conditions and, therefore, helps maintain body temperature within acceptable ranges [89]. Likewise, cases of excessive sweating will lead to a decrease in micronutrients including sodium in addition to minor amounts of potassium, calcium, and magnesium and results in an alteration of normal physiological functions.

Dehydration refers to the process where the loss of body fluid leads to hypohydration. Through a cascade of events, the metabolic heat generated by muscle contractions during exercise may eventually lead to hypovolemia (decreased plasma/blood volume) and, therefore, cardiovascular tension, increased glycogen consumption, altered metabolic and central nervous system function, and increased body temperature. In the most rudimentary conditions, weighing athletes before and after exercise helps to identify those that exceed a 2% weight loss, the level at which performance can be compromised [2]. Performance in many team sports is dependent upon cognitive function (e.g., attention, decision-making, memory, and reaction time), the execution of sport-specific technical skills (e.g., shooting, passing, and dribbling), and high-intensity physical abilities (e.g., sprinting, lateral movement, jumping, intermittent high-intensity running capacity) [90]. Specifically, in team sports like basketball, studies suggest that ≥2% hypohydration can potentially impact shooting performance, perhaps due to decreasing shooting accuracy and/or slowing the frequency of shot attempts.

Intuitively, the factors that elevate risk of hypohydration are those that increase thermoregulatory sweat loss (hot/humid environment and high exercise intensity) or limit fluid replacement. Sweating rate and/or fluid balance has been researched the most in team sports [90]. Moreover, sweating rates vary among players according to their position as well as total playing time. Handball players described a 0.8 ± 0.5 (0.0–1.4 kg) loss of body mass during matches, corresponding to 0.9 ± 0.34 (0.0–1.3%) of their body mass where the fluid intake was 1.2 ± 0.3 (0.6–1.5 L). Therefore, the total fluid loss observed during matches was 2.1 ± 0.4 (1.4–2.9 L) which represents 2.3 ± 0.4 (1.9–3.1%) of body mass. It is also important to note that no significant differences were observed between play positions [9]. Hypohydration, or factors associated with dehydration, are likely to be associated with practically important decrements in muscle endurance, strength, and anaerobic power and capacity. It is possible that body fluid loss (~3% body weight) may improve performance in body weight-dependent tasks like vertical jumping ability [91]. In any case, there are no studies related to cognitive function in handball.

Several authors [15] reported that game day stress can alter consumption habits leading to over- or underhydration. Given these considerations, the ACSM provides a series of hydration recommendations under special conditions [2, 89]. The ACSM recommends that people should drink approximately 5–7 mL/kg of body weight (~2–3 mL/kg) of water or a sports drink at least 4 h before exercise in order to optimize the state of hydration and to excrete any excess fluid such as urine [89]. In contrast, excessive hydration with fluids that expand the extra- and intracellular spaces considerably increases the risk of leaving the competition and does not provide a clear physiological benefit for performance. Thus, during exercise, drinking beverages containing electrolytes and CHO can help maintain fluid and electrolyte balance and exercise performance [89]. For many team sports, the capacity to sustain high-intensity efforts alternated with rest or lower-intensity periods throughout a game is critical to the success of an athlete. To date, two out of three studies have found a detrimental effect of 2–3% hypohydration on intermittent running capacity. Still, more research is needed, particularly on the sports that are highly dependent upon intermittent running capacity [90]. Therefore, the type, intensity, and duration of exercise should be considered as they alter the need for fluids and electrolytes.

Several considerations must be taken into account regarding the mineral and CHO content in beverages consumed. Sodium and potassium-containing fluids help replace sweat electrolyte loss, while sodium stimulates thirst and fluid retention at the same time that CHO provide a good energy source. In particular, beverages containing 6–8% CHO are recommended for exercise events lasting more than 1 h [2]. Prolonged exercise or heavy sweating, where the sodium replacement is not covered or there is excessive intake, may result in hyponatremia (serum sodium level below 130 mmol/L). Hyponatremia is more likely to develop in athletes who sweat less or consume excess water before, during, or after an event [89]. Therefore, normal food intake and drink is recommended after exercise to restore the state of hydration and replace fluids and electrolytes lost during exercise. Rapid and complete recovery from excessive dehydration can be achieved by drinking at least 450–675 mL of liquid per 0.5 kg of body weight lost during exercise. Thus, the consumption of rehydration drinks and salty foods as meals/snacks will help to replace fluid and electrolyte loss.

Significant hypohydration (>2%) has been reported most consistently in team sports including soccer. Although other sports have reported high sweating rates, fluid balance disturbances have generally been mild, suggesting that drinking opportunities were sufficient to provide most athletes with enough fluid to offset losses [90]. Even so, it seems that hypohydration is more likely to impair cognition, technical skill, and physical performance which are not routinely observed in team sports athletes. In future studies, it would be helpful to include higher levels of hypohydration. In addition, studies directly comparing the effect of hypohydration on different cohorts would be helpful in determining who may be more susceptible to the detrimental effects of hypohydration, from both a physiological (heat safety) and a performance perspective.

Conclusions

In nutrition for handball, as in other team sports, the physical and physiological demands are closely related to nutritional requirements. This chapter provides important information that allows us to know the nutritional status in handball players from a nutritional perspective. In this sense, future studies should examine the impact of different nutritional strategies in an individualized way with the aim of improving players' ability to sustain high exercise intensities during training and competition. Furthermore, future research should be conducted to examine the specific physical demands related to given technical playing actions (e.g., tackles, screenings, and jumping) and locomotive power output for a better understanding of energy, macronutrient, and micronutrient requirements as well as hydration patterns. An overriding reality, even when working with team sports athletes, is that an individual approach is needed to meet each athlete's nutritional and hydration needs.

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Part II

The Handball Medical Perimeter/Medical Preparation and Aspects

8

Assembling a Medical Team: The Medical Needs of a Handball Team

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8.1 Introduction

Elite handball is a dynamic contact sport with one of the highest injury rates of all Olympic sports [1]. Handball players also suffer from illness—10.9% of players participating in the 24th Men's Handball World Championship 2015 in Qatar were affected by illness during the event (the vast majority being due to respiratory tract infections) [2]. The biggest challenge for the medical team of an elite handball team is, therefore, to find the balance between managing the health of the players and optimising individual and team performance. Whilst a simplistic model would focus on the treatment of an injured player until return to health and then return to play (RTP), the reality is far more complex—with many players regularly training and competing with injuries of various degrees, due to the demands of their sport calendar [3]. In cases where players are unable to continue training or playing, the RTP decision-making process in elite sport is also challenging—many factors have to be taken into consideration, of which the future health of the player is only one aspect [4]. Creighton et al. proposed a three-step decision-based model for RTP in an effort to clarify and simplify the process [5]. They highlighted the many conscious and subconscious factors that play a role when deciding whether a player is fit to play. A critical element in the process of managing the health of the professional handball player is communication in a shared decision-making model. This should be supported by the correct organisational structure of the medical team in the handball club or organisation.

The purpose of this chapter is to describe a model for the structuring of medical and science support services to elite handball players in either a club or national organisational setting.

8.2 The Role of the Physician

It is important for any healthcare practitioner involved in handball to have a good understanding of, and passion for, the sport—including injury and illness epidemiology and clinical management. Perhaps one of the most significant

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changes in sports medicine in recent years is the explosion of global interest in the game. This popularity has resulted in a significant increase in professionalism in handball, not only in players but also in coaching and medical staff. Increased professionalism has resulted in better organisation of medical services and an expectation of increased specialisation of handball medical staff. These developments have been paralleled by the development of Sport and Exercise Medicine (SEM) as a core primary medical specialty in some parts of the world. SEM physicians now receive comprehensive specialist training in the management of not only injuries but also illnesses in sport. This signals a move away from the traditional injury-centred sports medicine model to one where the health and performance of the athlete are considered more holistically and where illnesses and chronic medical conditions, such as asthma and allergies as well as vitamin D deficiency, respiratory illness and gastrointestinal infections are equally important and managed proactively [6, 7].

The ideal handball team physician is a specialist SEM physician with a particular interest in handball medicine and years of experience in the sport. However, whilst this may be the ideal situation, it may not be possible in all centres in the world where handball is played. Training programmes in SEM vary by country (and still do not exist in all countries), but in many cases, up to 6 years of further study is required to prepare a SEM physician for their role in the holistic management of the health and performance of the athlete [8]. As such, SEM physicians are well positioned to take a leadership role in multidisciplinary teams providing comprehensive health management of the elite athlete [9]. Their training and experience allow them to understand not only the medical needs of the athlete but also the complexity of their professional environment and the demands of their sport.

One of the key characteristics of a team physician is the ability to communicate with all stakeholders and 'navigate' the team environment in such a way that players, medical colleagues and coaching staff all trust and value their opinion and recommendations. Without this ability, no amount of medical knowledge or clinical acumen will allow the physician to fulfil the role of case manager with success. Their unique position in the team means they have a responsibility towards not only their patient (the player) but also their employer (the team and coaching staff)—often with divergent interests. Their role is to find the balance between the two and propose a plan of action which not only addresses the concerns of both parties but which remains medicolegally and morally defensible.

The handball team physician should also be able to think laterally and be flexible—the team environment is not a traditional medical clinic room, and physicians often have to improvise and compromise due to external circumstances. Travelling to unfamiliar cities or countries comes with unique challenges, and the usual familiar medical network may not be available. The team physician may also find their role expanding to that of nutritionist, parental support (in youth teams), psychologist, massage therapist or 'kit man'—especially in those teams which do not have a large support or medical team. It can be very challenging to remain professional when players expect friendship, but it is crucial that the line between 'friend' and 'physician' remains well defined and transparent (Fig. 8.1).

The clubs and national federations that employ healthcare practitioners (SEM physicians, physiotherapists, etc.) in handball face the same challenge clinicians do: the often contradictory nature of players' health vs. performance goals. In traditional hierarchical structures and reporting models, and because of the large financial risks involved with professional sport, it is becoming increasingly difficult for clinicians and management alike to ensure sound clinical RTP decisions and to balance the needs of the athlete with the needs of the organisation. However, it is possible to address these issues with an appropriate organisational structure where the roles and responsibilities of all staff (medical, coaching, technical, administrative, etc.) and athletes are transparent—there needs to be a clear system of clinical governance and external professional appraisal. Medical staff accountability to independent professional authorities facilitates objective clinical decision-making, with reduced risk of bias (Table 8.1).

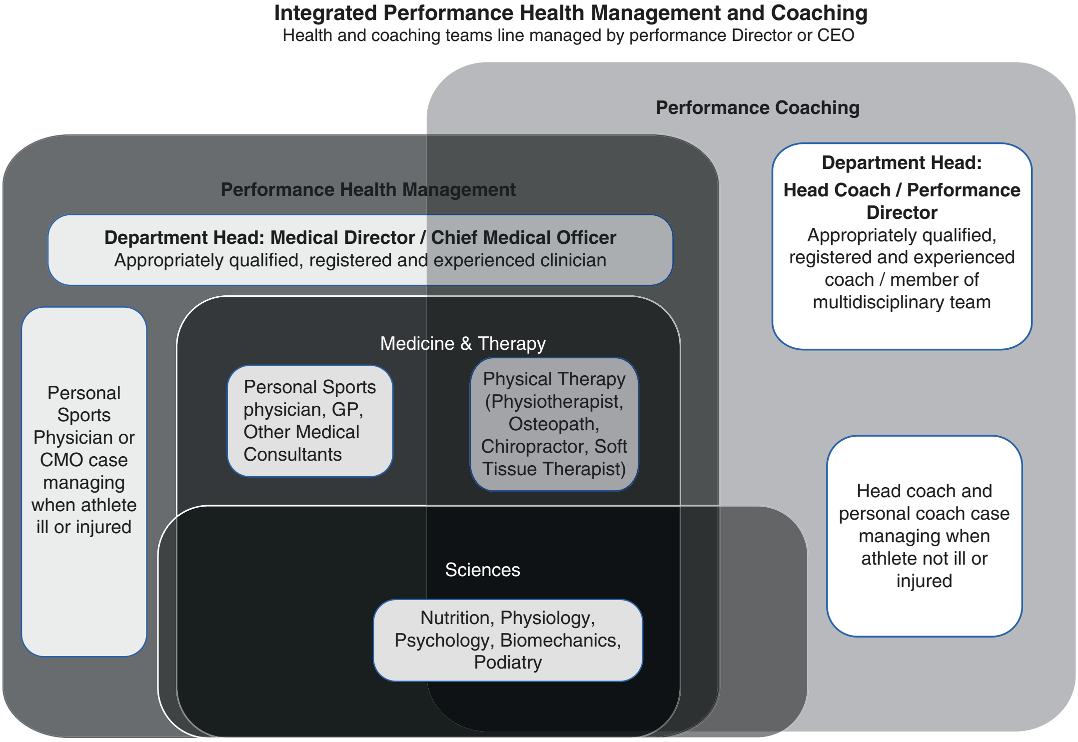

Fig. 8.1 Reproduced with permission [10]. The integrated performance health management and coaching model. All the specialties operate in the performance health and coaching 'box'. Specialist sports medicine physicians (led by the chief medical officer (CMO) or medical director (MD)) manage health (injury, illness and prevention); the head coach manages coaching. Both departments are managed by the performance or technical director or chief executive officer (CEO) depending on the structure and size/culture of the organisation/club. The health and coaching departments operate in synergy and 'independently' with appropriate autonomy at times

Table 8.1 Current challenges for handball sports physicians and suggested solutions (*adapted with permission* [10])

Challenge	Solution
Physicians lacking specialist training or practicing in isolation Physiotherapists managing the total health of elite athletes	Aim to employ only well-qualified specialist SEM physicians or physicians with extensive handball experience to manage the total health of athletes Physiotherapists are qualified to manage musculoskeletal health but not overall health
Physicians are employed by clubs—might influence clinical decision-making	Clear role definition with internal and external clinical governance (e.g. appraisal and revalidation process by the appropriate external bodies such as the medical council in the countries in which they are practicing)
Physicians are clinically line managed by non-medical team members or non-clinicians. This challenges athlete medical confidentiality, ultimate clinical responsibility and access to medical records	Employ appropriately qualified sports medicine physicians with contractual arrangements detailing their ultimate clinical responsibility Culture and contracts within sporting organisations should consider the issue of medical confidentiality
Managers or coaches refer to specialist medical services without involving the medical team	The chief medical officer or medical director should be ultimately responsible for all the clinical medical aspects including referring athletes for other specialist investigations or treatments. Athletes have the right to more than one medical opinion—develop and agree on a clear referral protocol
The head coach influences/overrules clinical decisions by the medical team	Within a performance environment, the clinical advice may not always be heeded. The performance director to whom the medical team is accountable may, in conjunction with the athlete and in receipt of the medical opinion, choose an alternative path. The procedure and documentation around this process should be clear

8.3 Proposed Integrated Performance Health Management and Coaching Model

In the traditional sports medicine model, the team physician is the primary point of contact for the athlete [11]. A more current (improved) model recognises the fact that the athlete may have a variety of 'nonphysician' sports medicine practitioners who provide a primary medical point of contact. This group can include physiotherapists, nutritionists, podiatrists, chiropractors, etc. Whilst this allows for a multidisciplinary approach, it can create a situation where athletes find themselves trying to understand and assimilate advice from several different and disjointed sources and eventually having to find an appropriate solution on their own or with the help of a coach (who may not be best equipped to make medical decisions). A better model is one where the team physician—who ideally should be a SEM physician—acts as a 'case manager'. Whilst this physician may not always be the first point of contact for a player in the 'team behind the team', they will integrate all the available information and advice and formulate it in a recommendation, which considers not only the health but also the performance of the player. This approach encourages the player to make an informed decision, in discussion with all relevant stakeholders, including coaching staff [9].

The simplistic interpretation of the current multidisciplinary sports medicine model is that the role of the team physician is to *protect the health and welfare of the player* [12]. The application of the principles of 'evidence-based' sports medicine is one of the key requirements. This involves the skilful integration of 'best practice treatments' based on high-quality scientific evidence, player and practitioner experience and the individual and team expectations. The science is often based on large population group studies (usually demographically very different from the 'average' elite athlete or player) and may include objective outcome measures and precise diagnoses, whilst experience and expectations are contextual and impossible to isolate from local culture and practices. The reality of elite sports is that player health is a spectrum ranging from complete wellness (whilst acknowledging that possible intrinsic and extrinsic risk factors might influence this state) to multiple existing injuries and illnesses—especially in the older player. Players tolerate this spectrum of health in order to perform consistently. When the player is viewed holistically, it becomes clear that making the best performance decisions sometimes compromises the player's 'health and welfare'. Therefore, in an improved model, the SEM physician's primary role is not simply the 'health and welfare' of the player but rather assimilating information and providing a safe framework for player decisions that balance health and performance goals.

Clever decision-making about training and competing is essential not only for the player but also for the coaching staff. The secret of successful performance is to treat the player holistically and to focus not only on any current injury, but also on the overall function of the player-which includes strategies to reduce risk for injury, or illness, as well as management of existing health issues. In the case of team sports, such as handball, consideration should also be given to the player's role in the team and the impact any decision will have on the team. These aspects require understanding and input from coaching staff and should be considered when structuring medical services and assembling a medical team for handball clubs or organisations.

The *integrated performance health management and coaching model* focuses on how two key departments (*health* and *coaching*) work together to improve performance—this model can also apply to elite handball [10]. The two departments should ideally function as two independent departments but work towards one common goal under a single management umbrella: success and performance of the team. In order to achieve this, it is important to clarify the roles and responsibilities of the staff in each department.

The SEM physician (chief medical officer or medical director in the case of larger clubs or national federations) leads the health department. This person should ideally be a specialist

SEM physician or possess an alternative sports medicine certification (certificate, diploma, master's degree) in countries not yet having this specialty, with experience in handball medicine, and should have an overall clinical and medicolegal responsibility for all the players. Their primary responsibility is to oversee the health of all players in the club and to work with the coaching department to ensure any health-related decisions are based on the principles of shared decision-making, including informed consent when appropriate. This is to achieve a balance between health and performance of the athlete and the team.

The head coach, who has overall responsibility for all other coaching staff, including the strength and conditioning or fitness coaches, leads the coaching department. In the proposed *integrated performance health management and coaching model* applied to handball, the coach should provide valuable input regarding training principles to achieve a particular performance goal, as well as players' values and preferences. The coach should have a working knowledge of important injuries and illnesses in handball and an open-minded attitude to receiving information from medical staff about treatment and prevention of injuries and illnesses in handball.

The performance or technical director or chief executive officer, depending on the size of the organisation, has overall responsibility for managing the two departments and implements the performance strategy of the club or organisation.

8.4 The Medical Team in Handball

8.4.1 The Team: Relationships, Roles and Responsibilities

The role of the medical team is to anticipate and manage the medical and performance needs of the handball team. It is therefore crucial that the members of the medical team are familiar with the sport, in order to understand the physical, physiological and psychological demands on the players. The exact size and composition of the medical team are dependent on the competitive level of the handball team, as well as financial considerations. Most professional clubs or national teams will have a multidisciplinary medical team consisting of various combinations of physicians, physiotherapists, massage therapists, nutritionists, physiologists, psychologists, podiatrists or other sports medicine practitioners. Even when the medical team is much smaller, an external network of supportive colleagues may be able to provide a multidisciplinary setting. As important as the qualifications and experience of the medical team is the ability to work together as a team, and consideration should be given to developing a code of conduct that should be officially endorsed by all team members.

The team physician (or chief medical officer/medical director) is a medical doctor, ideally with specialist SEM training and experience, and has overall clinical and medicolegal responsibility for the players. In smaller clubs, there may be only one team physician (or no physician at all), whereas in larger clubs and national organisations, the chief medical officer/medical director may be supported by other SEM team physicians. All club and team physicians should have a thorough knowledge of handball and be experts in the current best practice in handball medicine, as well as the protocols and requirements of handball events. They are the case managers of all players with existing or chronic injury or illness. Their role includes injury and illness prevention and education of players, coaching and other staff. They are supported by a team of handball-specific medical and sports science experts who can assess biomechanics and risk factors, in order to not only treat injuries but also prevent them.

The team physician (or chief medical officer/medical director in the bigger clubs) has the overall responsibility for ensuring that medical services are in place. This includes setting up the infrastructure (physical and organisational) to ensure an integrated multidisciplinary approach to care for the players, as well as ensuring adequate documentation and medical record keeping. Other responsibilities might include budget planning for the medical department, pharmaceutical dispensing, communication with all stakeholders and education. Clinical services include management of player health, as well as performance optimisation and screening of potential new players. Other important assignments for the medical team are injury and illness prevention, objective testing before RTP clearance, medication and nutritional supplement control. The physician also has final clinical and medicolegal responsibility for athlete health and has a responsibility towards other health practitioners in the medical team to provide education as part of a well-structured Continuous Professional Development Plan.

The balancing act provided by well-trained and experienced SEM physicians and physiotherapists employed by the handball club or organisation is an important element to ensure the best possible care, accountability and outcome under the direction of senior management. With specific regard to the responsibilities of the physician and the physiotherapist, the physician is responsible for the diagnosis and initial management of illness and musculoskeletal injury. The physiotherapist is responsible for the rehabilitation and exercise prescription required in the management and prevention of injury and in liaising with the coach to ensure appropriate transition in return to training and competition.

The relationship between a team physician and a coach is important for player success, especially when travelling to major competitions. A relationship of mutual trust and respect will improve the quality of performance decision-making and player health.

Players and coaches should work in close partnership with the medical team. Decisions must be based on an informed process taking into account the relevant health aspects and the specific individual and team performance goals.

8.4.2 The Player Care Model

It is important to consider how the medical team utilise their expertise to manage the health of the player. In our current models, there are often two opposing approaches to patient care:

Evidence-based medicine (EBM) has become more and more important over the past 20 years; this is also true for sports medicine, with the establishment of specialist training programmes in different parts of the world. In the traditional EBM model, clinicians apply five steps:

- Asking the clinical question
- Finding the best scientific evidence
- Appraising the evidence
- Making a decision
- Evaluating performance

In this model, it is up to the clinician to consider all the potential biases, which may affect decision-making. The practice of EBM however has changed with a significant focus on the skilful integration of science and preference/experience using a shared decision-making approach.

In the ***preference-based (athlete-centred)*** model, the player has specific preferences and makes the decisions, but there are significant deficiencies, especially with regard to informed consent and shared decision-making. These deficiencies contribute to the 'preference-practice' gap.

Quill and Holloway [11] have highlighted the conflicts between these two models and developed a five-step framework for reconciling the differences between the traditional 'evidence-based' and 'preference-based' medicine, which they believe can help in leveraging the best of both approaches. The principle on which this solution is based is that clinicians should provide recommendations and guidance based on their medical knowledge and their understanding of the patient's values but then ultimately allow patients the final authority over major decisions. However, actualising this process is not simple. It is even more complicated in the setting of the elite handball team, where decisions regarding a single player's fitness can affect the entire team. The proposed steps for implementation of the framework are (adapted to the elite handball team setting):

1. Team meeting: Decide which key people around the team should be involved (player, coach, other team representatives), and clarify the medical evidence about the clinical

situation—including benefits and risks of various treatments, as well as providing no treatment at all.

2. Sharing information and expertise: Team physician shares clinical information about the situation; the player shares goals, values and priorities; and the coach shares performance goals and priorities, for both the individual player and the team.
3. Consider biases and emotional responses: This step corresponds to the critical appraisal step in the EBM model but needs to also consider 'hidden' biases and emotions that may not be evident in the initial conversation. In the setting of the handball team environment, there may also be subtle pressure from coaching and other staff, as well as the team, placed upon the player. If there seems to be any uncertainty or ambivalence regarding the proposed management plan, then enough time should be given for deeper consideration of the issues, even though there may be time pressures in the seasonal calendar.
4. Integration of the evidence-based and preference-based models: The team physician must consider all the information gained by the evidence as well as the player's and coaching staff's preferences and performance goals and make a recommendation. It is crucial that the team physician communicates effectively to players and coaches and ensures that they understand the risks to health or performance or both. The attitude to risk is contextual and may vary considerably between player and coaching staff or one event to another (e.g. a local club event, compared to the Olympic Games). The final decision regarding the treatment rests with the player. The aim of the integrated performance health model is to ensure that at this step all stakeholders have been heard and that the final decision made by the player reflects a consensus between player, medical team and coaching staff.
5. Evaluating performance: As is the case with the traditional evidence-based model, the clinical outcomes should be monitored and changes to the management plan implemented as necessary.

In summary, the skilful and contextual practice of EBM integrates the best science with experience, preference and expectations in an environment of trust, accountability and shared decision-making [13].

8.4.3 Infrastructure

Unlike medical care in traditional models, the care for elite players is often provided outside the hospital or a standard medical setting—in a club clinic, in the gym, on the sidelines and even on the field of play. When the team is travelling, a hotel room usually becomes the 'field-clinic' or 'field-hospital'. It is therefore important that the medical team ensures that the physical infrastructures (including equipment and consumables) are in place and regularly maintained, in the same manner as it is usually performed in a more traditional medical environment. It is vital to maintain good hygiene practices, especially when minor procedures (such as suturing) are performed in a club or stadium setting.

When referring to 'infrastructure', the first thing that often comes to mind is the physical environment, such as the clinical assessment room and rehabilitation facilities at the club. However, it is even more important to introduce the 'administrative' infrastructure that will facilitate effective and open communication and a multidisciplinary approach to problem-solving, than to have the latest gadgets on the market.

It should be a priority for handball clubs or organisations to develop appropriate clinical settings to deliver medical and therapy services. Whilst this may be more easily achievable in the club setting, where all players regularly meet in the same venue, it can be a challenge in national team environments, where players may be in geographically diverse locations. In this situation, it becomes very important to have a national structure and communication model whereby clinical information and decisions can be shared between clubs and the national team in a way that facilitates continuity of care for the player and ensures consistency of decisions focused on achieving balance between health and performance. This can be challenging when performance goals and priorities are different between clubs and national teams and the player experiences pressure for an early return to play from coaching staff.

Integrated problem-solving should be promoted by the use of a multidisciplinary team of physicians, physiotherapists and other sports medicine practitioners ideally performing consultations together and discussing diagnoses and treatment strategies in the context of ongoing physical loading in training and competition.

8.4.4 Continuous Health Monitoring and Electronic Medical Record Keeping

As with any other medical practice, a robust medical documentation system is essential. In this regard, it is recommended that the handball club or organisation employ an electronic health record (EHR) system, which not only simplifies the process of documentation but also provides an excellent tool for health monitoring and communication across disciplines. EHRs can be tailor-made or bought ready-made 'off the shelf', with various degrees of customisation possible. Perhaps one of the most useful features of an EHR in the sporting setting is the ability to provide colour-coded guidelines to players and coaching staff, as well as other medical staff, on players' readiness to train or play. This is particularly useful for players who compete in more than one environment or for national organisations that oversee many different players in geographically diverse locations. Obviously, utilising this function requires a pre-existing infrastructure where clubs and national teams communicate freely and share decision-making—something that currently remains a challenge in many instances. However, any individual team can utilise this function for decision-making and communication in their own setting. One of the most common examples of this is the 'traffic light' system of red, orange and green—where players are classified according to their readiness to return to play and competition, based on their current injury and illness status [10].

In such a model, players are regularly monitored and assessed and based on current controlled or uncontrolled medical conditions are assessed as follows:

- Green: healthy, low risk of injury or illness
- Orange: some health issues, moderate risk
- Red: significant current or ongoing medical issues, high risk

It is important to appreciate that this system does not determine readiness to train or compete per se. Rather, it acts as a tool to facilitate shared decision-making with the player and the coach in an elite sporting environment where risk-taking is inevitable. In this scenario, the physician provides the necessary information for the player and the coach to weigh the risks and then make an informed decision regarding the athlete's readiness to accept these risks or not. No system is perfect, and critics of this model will question how well-informed athletes are and how well they are able to make a truly independent decision [12].

A similar approach has been proposed for the pre-participation examination (PPE) when screening athletes [14]. The classification may be as follows:

- Class 1: healthy, low risk
- Class 2: some health concerns, moderate risk
- Class 3: significant concerns, great degree of risk
- Class 4: risk too great from a *medical* point of view

The pre-participation screening process has obvious benefits, but its limitations also have to be recognised [15]. Traditionally, the pre-participation examination (PPE) is used either:

- To screen new players before signing a contract with a club or team
- To perform a periodic health examination in existing players (in which case it can be described as such a PHE)

As described by Bahr, the PHE is a very useful way of establishing the athlete's current health status and acts as an entry point for medical care of the athlete [14]. Other benefits may include building rapport between the medical team and the athlete, reviewing medications (and avoiding inadvertent doping) and establishing a performance baseline for the athlete when in a healthy state. However, it is questionable whether the risk of injury can be predicted by the PPE. Even in the case of predicting the risk of sudden cardiac arrest in athletes with significant cardiac pathologies (such as hypertrophic cardiomyopathy or arrhythmias), there are significant ethical implications when advising athletes regarding fitness to compete.

Once the medical team has ensured that the athlete is well informed about treatment options and possible consequences, they should respect the player's decision regarding acceptance of risk and not interfere unnecessarily, especially if the player's performance may be affected in the process. However, in the case of new contracts being offered, the decision regarding the acceptance of risk is with the club or team senior management.

8.4.5 Educating the Medical Team, Coaching Staff and Players

In order to maintain a high performance level by the medical team and adhere to the highest standards of medical care, it is important to engage all the members of the medical team in updated educational activities—both within the team and outside the team. This includes activities such as periodic life support courses and exercises, team physician courses and sports-specific conferences. In football, for example, the 'UEFA football doctor education programme' and the 'FIFA diploma' were established for these purposes. It is also important to utilise the different medical team members' specialty to educate the other members on issues within their scope and optimise decision-making as well as treatment strategies and protocols within the team.

Establishing a good and ongoing communication between the medical team and the coaching staff as well as the players is important and essential not only for a positive work environment but also to implement new ideas and concepts more efficiently (i.e. injury prevention concepts, nutrition). A recent study focusing on injury prevention education for rugby coaches has shown a substantial influence on players' training approach and behaviour, favouring injury prevention-related activities/behaviours [16].

It is advised that the medical team would be well educated and remain updated on doping issues as these changes constantly. It is also advised to educate the coaching staff not to administer any substances or supplements and players not to independently use or share such substances with their teammates without consulting the medical team first. This is a crucial issue and may result in substantial medicolegal and even career ending consequences for medical team and coaching staff members as well as players.

8.5 Conclusion

Providing medical services for an elite handball team, regardless if the setting is national or international, and regardless if it is a male or female team, is a challenge, which should be tackled with the best tools available to the clinician. The new suggested model of sports medicine focuses on health provision by specialised SEM physicians who have the necessary training and experience to offer holistic and expert care to handball players, acting as case managers in a multidisciplinary team of carers. The traditional 'evidence-based' care models are currently being replaced with an integrated performance-focused approach where the team physician, player and coach make decisions which balance athlete health with performance in a setting where all stakeholders share in the decision. This approach to the practice of EBM reflects the reality of elite handball—where players will often take risks regarding their health in order to optimise performance. It is the role of the team physician to ensure information provided by multiple specialists have been assimilated, that player and coach preferences and biases have been considered and that the player has been fully informed about recommended treatments and consequences, before health decisions are made. It is then also the medical team's responsibility to ensure ongoing monitoring and support of the player's health and performance.

It is therefore important to have a robust plan in place for the organisation of medical support services to elite handball teams, as well as a protocol for decision-making in the elite handball environment, supported by the health and coaching departments of the team. Implementing the proposed integrated performance health management and coaching model will ensure that athlete health issues are balanced by performance considerations and that both health and coaching departments can work towards one common goal.

8.6 Take-Home Message

In the modern era of handball development, we have a responsibility to propose a new model of specialist and multidisciplinary, integrated medical care for handball players—which addresses not only the players' health but also their performance.

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9

The Role of Pre-Participation Assessment (PPA) and Screening in Handball

Stephen Targett, Tone Bere, and Roald Bahr

9.1 Introduction

There are several different terms used in the literature to describe the routine medical assessment of athletes. The more common terms seen in the literature are periodic health evaluation (PHE), pre-participation evaluation (PPE) or precompetition medical assessment (PCMA). Although distinction could be made between these different assessments, in essence, the primary goal of all of these assessments is the same, namely, for the medical staff to get to know the current health status of their players. To avoid confusion the term PPA will be used to refer to such assessments for the rest of this chapter.

Screening, in a medical setting, is defined as a strategy used in a population to identify the possible presence of an as-yet-undiagnosed disease in individuals without signs or symptoms. Although the PPA is often referred to as a 'screening medical' by players and medical staff, strictly speaking, this is inaccurate as screening activities only constitute one part of the PPA. The role of screening in a PPA will be reviewed in the section on screening.

9.2 The Primary Goal of the PPA: Reviewing the Player's Current Health Status

As stated above, the primary goal of the PPA is to review a player's current health status, and this should be repeated on a regular (probably annual) basis. The basic make-up of the PPA is the same for most team contact sports; however, there will be some minor differences due the differing demands of the sports. Assessing the current health status is made up of several components:

9.2.1 Review Current Medical Problems and Injuries

This is a good opportunity to review any known medical conditions to ensure optimal treatment—for example, in a player with asthma, checking for any symptoms and compliance with any preventative medications, the pattern of use of beta 2 agonists and an assessment of inhaler technique

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may be required. Excessive or inappropriate use of beta 2 agonists will need to be managed appropriately.

For handball players with a known chronic overuse problem such as shoulder pain associated with throwing or anterior knee pain associated with jumping, a review of the treatment plan is indicated and will often involve asking about symptoms over recent weeks, effect on performance (if any) during training or playing, compliance with and correct application of any prescribed rehabilitation exercises and performing a clinical examination.

Reviewing any injuries sustained in the previous season may also be appropriate to check that rehabilitation has been completed and that there are no ongoing symptoms or residual issues, for example, ongoing restriction of range of movement of ankle dorsiflexion or subtalar joint range of movement or any residual strength/balance deficits following an ankle sprain.

9.2.2 Pick Up Unreported Injuries/Medical Problems/Symptoms

Many handball players are reluctant to report any symptoms or injuries to medical staff in the belief that if the coach finds out it may negatively affect their chances of selection. It is not uncommon to find out that a handball player has played the last few weeks of the season with unreported symptoms such as shoulder pain with throwing or low back pain.

Specifically asking about any unreported symptoms, especially of the shoulder, knee, elbow (especially in goalkeepers) and spine and performing a targeted physical examination are probably best done at the end of the season, before the off-season break, so that any treatment can be planned over the off season. Addressing issues in the preseason period can be tricky as this is often the period of physical conditioning, and time for a rehabilitation programme is restricted and may compromise preseason conditioning.

9.2.3 Check Family History

Checking the family history is an important component of cardiac screening, especially a family history of a sudden cardiac or unexplained death in a first-degree relative under the age of 35, as well as certain inheritable conditions associated with sudden cardiac death such as Marfan syndrome or cardiomyopathy.

9.2.4 Review of Medications and Supplements

It is important to carefully go through with the handball player all medications (both prescribed and ‘over the counter—OTC’) and supplements that they are taking whether it be intermittently or on a regular basis.

The main reason for doing this, apart from providing another check for any unknown medical issues and for appropriateness of medications, is to check that the player is not taking any WADA-prohibited substances. Common causes of inadvertent consumption of prohibited substances are:

- Taking OTC medications without first checking with team medical staff (or with online resources such as globaldro.com)
- The use of unapproved supplements
- Prescription of prohibited substances by medical practitioners not aware of WADA regulations who may falsely reassure the player that there is no issue (common pitfalls being probenecid for soft tissue infections, oral corticosteroids for dental procedures or narcotic medications used as part of a general anaesthetic)

It may be appropriate to remind the player of the hazards of taking supplements, the contents of which are not regulated closely like prescription medication. Studies have shown that many supplements contain WADA-prohibited substances that are not listed in the ingredients list [1]. The use of only team-approved supplements should be encouraged.

This is also a good opportunity to remind the handball player of the WADA regulations, that the players themselves are responsible for any supplement or medication that passes their lips and the importance of first checking any medication or supplement with team medical staff. Players in WADA-registered testing pools should be questioned to check that they are aware of and are complying with their whereabouts obligations.

9.2.5 Review Recovery Strategies

If the handball team does not regularly monitor recovery strategies through the season, then the PPA can be used to ask players about matters such as their sleep patterns, nutrition and methods of monitoring hydration and may identify any areas of concern that require intervention. Other areas for discussion may include strategies to minimise the effect of prolonged or cross time zone travel.

9.2.6 Opportunity for the Player to Ask Questions

It can sometimes be difficult for players to get some one-on-one time with medical staff during the season as treatment areas are often not private. If possible, a private consultation area should be used for at least part of the PPA to allow the player an opportunity to ask any personal questions or discuss sensitive matters that they do not want their team mates to overhear (Fig. 9.1).

9.2.7 Opportunity to Get to Know Players Better

Following on from the previous point, the PPA is a good opportunity to get to know the player better and build up the doctor-patient/doctor-therapist relationship. If the player trusts the doctor and medical staff, they will probably be more likely to report symptoms earlier and be more compliant with treatment and rehabilitation programmes.

After a head injury, the signs of concussion can be subtle and easily overlooked. Knowing

Fig. 9.1 The PPA is an opportunity to get to know the players better

a player well may enable team medical staff to detect subtle behavioural or mood changes, which are sometimes the only outward sign of a concussion. These might be overlooked by someone who is not as familiar with the player.

9.3 The PPA Is a Good Opportunity to Undertake Other Medical-Related Activities

In addition to the primary goal of reviewing the current health status of the handball player, there are several possible secondary goals that might also be achieved by a PPA:

9.3.1 Pre Competition Medicals/Visas

In some settings, a medical assessment following a certain template is required before taking part in an international or national competition. The PPA is a good opportunity to complete such a medical assessment and will highlight any requirements, such as an electrocardiogram or echocardiogram, which may not be easy to access for all teams. Keeping up to date with any requirements is important as these may change from year to year.

The other advantage of performing these assessments well in advance is that approximately 5% of players will require further cardiac assessment and investigations after an ECG. If an ECG is required by the governing body, trying to find a cardiologist with the appropriate experience in sports cardiology and arranging for an assessment at short notice in the period leading up to a competition adds unnecessary stress to the process for player, medical and coaching staff and teammates if aware and can negatively affect preparation for an event.

Handball is a global sport and sometimes visas are required when playing overseas – this can vary from person to person, depending on their nationality or place of recent abode, and visa requirements change over time. Some visas have medical requirements such as an immunisation certificate or tests to confirm the absence of parasitic diseases. Again, trying to meet such requirements can take time and may result in a player being unable to travel with the team. Planning ahead and avoiding any such nasty surprises can avoid any unnecessary embarrassment.

9.3.2 Prevention Initiatives

An outbreak of infectious disease such as influenza or gastroenteritis amongst a team can be disastrous, especially if it occurs close to an important competition. Bere et al. [2] showed that illnesses were more prevalent than injuries during the 2015 World Handball Championships in Doha. An increased risk of medical conditions has also been noted in professional athletes following time zone travel [3] and the lowered immune status of highly trained athletes, living in close quarters with other team members, and poor personal hygiene practices may contribute to this increased risk.

As mentioned in the previous section, planning ahead for travel to areas where infectious disease prophylaxis is required should also be done in the preseason period, in particular the administration of any immunisations that may be required.

Preventative measures such as immunising against influenza and having clear hand washing, sneeze and cough procedures can be covered as part of the PPA. Having a strategy for the isolation of affected players and other measures to prevent spread of the disease during an outbreak should also be prepared as part of the preseason planning.

9.3.3 Education

The PPA is a good opportunity to discuss lifestyle issues such as alcohol and recreational drug use, safe sexual practices or safe driving tips (wearing safety belts and avoiding drinking and driving). What topics are covered will be context specific and may need to be done on an individual basis but can also be done in a group session.

Handball coaching and other management staff traditionally have little to do with the PPA process. The PPA is often performed in the preseason period when there are many demands on players' time (fitness testing and conditioning, coaching interviews and planning, team meetings, sponsorship demands, outfitting, etc.), and as a result, medical staff can struggle to get sufficient access to players for a PPA. Involving handball coaching and fitness staff in PPA planning can help to educate these groups about the benefits of the PPA, allows them to buy into the process and as a result should make it easier to find time to schedule the PPA and most importantly get support from coaching staff for any rehabilitation recommendations following the PPA.

9.4 The Screening Components of a PPA Should Be Planned Carefully to Ensure that the Goals Are Achievable Given the Available Resources

As stated in the introduction, screening is defined a strategy used in a population to identify the possible presence of an as-yet-undiagnosed disease in individuals without signs or symptoms. There are three areas where screening is commonly employed in a PPA setting:

- Cardiac screening
- Musculoskeletal (MSK) screening
- Screening for minor medical problems that might affect performance

The first two, cardiac and MSK screening, have dominated the literature about the PPA over recent years, but despite this, there is still a significant amount of debate about these topics. A detailed review of these topics is beyond the scope of this chapter.

The principles of screening handball players are no different to screening the rest of the population. The main criteria are that the condition being screened for is an important health problem (a reduction in dominant shoulder ROM will be far more significant to a handball player than to a member of the general public, however), that there is a detectable early stage, that treatment at an early stage is of more benefit than at a later stage and that a suitable test is available to detect disease in the early stage. The principles, often referred to as the Wilson-Jungner criteria, are outlined in a paper published by the World Health Organisation [4] and are just as relevant today as when they were published.

9.4.1 Cardiac Screening: Identifying Those with Medical Conditions Associated with Sudden Cardiac Death

A series of high-profile sudden cardiac deaths in elite footballers in recent years has led to a significant amount of media attention and stimulated vigorous debate, prompting many sporting bodies to recommend or mandate cardiac screening.

The rationale behind cardiac screening is to identify those with medical conditions associated with sudden cardiac death and to prevent or reduce the mortality rate by risk stratification of individual cases followed by appropriate disease management and advice regarding appropriate activity levels.

Unfortunately, the marked reduction in sudden cardiac death in sport seen in the Veneto region of Italy following the introduction of a mandatory pre-sport cardiac screening programme in the 1970s [5] has not been reproduced elsewhere, leading to widespread debate about whether and how cardiac screening should be performed. Much of the debate has been about whether or not to include ECG as part of cardiac screening.

What is often not understood (or forgotten) is that cardiac screening of athletes is not perfect. Like all other forms of screening, there are false positives (people without disease who have a positive screening test) and false negatives (people with disease but a negative screening test) as well as true positives (i.e. people with diseases associated with sudden cardiac death) and putting measures into place to ensure appropriate management of each of these scenarios needs to be taken into consideration when planning a cardiac screening programme (Fig. 9.2).

Fig. 9.2 ECG improves the sensitivity of cardiac screening compared with history and physical examination

9.4.1.1 False Negatives

Studies have estimated that history and examination will identify only 20% of cases of medical conditions associated with sudden cardiac death (SCD) [6]. The addition of an ECG will improve the sensitivity to about 60%. So, although the addition of an ECG will significantly improve the sensitivity of screening, up to 40% of conditions associated with SCD will still be missed.

False negatives can lead to *the* following issues:

- Players who have 'passed' cardiac screening may be falsely reassured and not report symptoms that subsequently develop.
- Doctors may also be falsely reassured and ignore symptoms that develop after a player has 'passed' cardiac screening.
- Organisations who have arranged for cardiac screening may overlook implementing measures to manage cardiac arrest during exercise, arguably the most important intervention for the prevention of SCD. Early access to a fully maintained automatic external defibrillator and the preparation of a well-practiced emergency action plan are critical steps in the management of sudden cardiac arrest.

9.4.1.2 False Positives

Cardiac screening questionnaires lead to a significant percentage of positive responses (15–31% at high school or 27–37% college athletes [6]) which all require further interpretation by someone with experience to determine if they are significant and need further investigations. Distinguishing between the normal physiological adaptations to exercise and pathological changes on an ECG can sometimes be difficult, and interpretation of an athlete's ECG should be performed by someone with adequate training and experience. Recent advances in the interpretation of athlete ECGs have significantly reduced the false positive rate to about 2.5–6.6% [6].

9.4.1.3 Follow-Up of Positive Screening Results

Cardiac screening will produce positive results, some of which will be false positives and some true positives. Having access to resources to further investigate positive results in a timely manner should be established prior to commencing a screening programme. This will include adequate financial resources as well as access to a sufficiently experienced sports cardiologist. The interpretation of abnormal cardiac tests in players as well as the immediate and ongoing management of players with conditions associated with sudden cardiac death is complex and can be contentious, particularly if a player's career is at stake.

Cardiac screening does not always produce black and white results—sometimes the screening is abnormal but does not meet the criteria for a particular condition—sometimes called 'grey cases'. Such cases need to be followed up and managed by specialists with sufficient expertise.

9.4.1.4 In Summary: Cardiac Screening Should Be Planned Carefully

There is no one-size-fits-all solution for the cardiac screening of handball players. The decision on whether or not to screen or how to screen should be made on an individual basis [6], after first considering the risk of the population being assessed and the available resources (money and access to equipment and specialist support). Being prepared to deal with false positive and negative tests, as well as people with true positives, is a critical part of planning.

9.4.1.5 Don't Forget What Is Probably the Most Important Measure to Prevent Sudden Cardiac Death

Regardless of the decision about cardiac screening, efforts should be made to optimise the management of SCD, with early access to a properly maintained defibrillator and a regularly practiced emergency action plan (so that everyone involved understands and can easily perform their roles in an emergency).

9.4.2 Musculoskeletal Screening: Identifying Which Players Will Get Injured Is Not a Realistic Goal

However, there are reasons why musculoskeletal screening in handball may be beneficial. These include:

- To detect abnormal findings on physical tests that could require further follow-up
- To perform baseline testing that can be used in return-to-sport decision-making

The musculoskeletal screening programme should be adapted to the specific characteristics of handball with an emphasis on those areas at highest risk of injury. For acute injuries, the most common locations are the knee and ankle, while the shoulder is the site for most overuse injuries.

Given that athletes from most sports are sometimes slow at volunteering symptoms with the standard response to the question 'do you have any injuries?' being 'no', a standardised questionnaire such as the Oslo Sport Trauma Research (OSTRC) Overuse Injury Questionnaire, which asks specific questions about pain levels and effects on sport performance and participation, can be useful for screening for hidden problems prior to the MSK examination and can then be used to monitor for the development of symptoms during the season [7].

Similar to other overhead sports, handball places a large amount of repetitive stress on the shoulder during training and competition, and as a result, overuse shoulder problems are common in handball. Clarsen et al. [8] reported an average prevalence of shoulder problems during the season of 28% in elite handball players, with 12% of all players reporting a moderate or severe restriction in performance due to shoulder problems.

Several risk factors have been associated with shoulder pain in elite handball, e.g. scapular dyskinesis, reduced total glenohumeral range of motion, reduced external rotation strength and increased weekly handball load. Interestingly, an exercise programme aimed at increasing glenohumeral internal rotation, external rotation strength and scapular muscle strength, as well as improved kinetic chain and thoracic mobility, has been shown to reduce the prevalence of shoulder problems amongst elite handball players [9].

Unfortunately, predicting future injury risk through the use of screening tests has proven to be an unrealistic goal. Even though several risk factors for shoulder problems have been identified, and there seems to be a relationship between a risk factor, e.g. external rotation strength and future risk of shoulder injury, it is not possible to set a cut-off value separating high-risk and low-risk players with sufficient accuracy.

In addition, we do not know whether an intervention programme targeting athletes identified as being at high risk is more beneficial than the same intervention programme given to all players. Thus, injury prevention interventions (which are usually cheap, non-invasive and easily administered) should be applied to the whole team, rather than spending time trying to identify, through screening, a group of athletes to exclude from a potentially beneficial intervention.

9.4.3 Screening for Minor Medical Problems that Might Affect Performance

Both iron deficiency and asthma have been identified as common medical problems that may be asymptomatic, yet negatively affect athletic performance.

Asthma is common in elite sport, affecting up to 8% of Olympic athletes, but is more common in sports where there is exposure to allergens (e.g. chlorine in swimming sports, pollen or pollutants in outdoor sports), exposure to cold air or in athletes with large ventilation rates (e.g. rowing). The prevalence of asthma in handball was reported to be 7.7% in one small study [10]. Bronchospasm may only occur when triggered by exercise rather than having background asthma. Athletes may not report symptoms such as shortness of breath, wheezing or cough associated with exercise, believing them to be a normal symptom of exercise, and respiratory function testing is required to make the diagnosis.

The traditional method of measuring drop in FEV_1 (1 second forced expiratory volume) while symptomatic or after a challenge test (exercise, mannitol or methacholine) has been reported to miss some asymptomatic athletes with exercise-induced bronchospasm and more recently eucapnic voluntary hyperventilation (EVH) has been proposed as the gold standard for the diagnosis of EIB although this requires specialised equipment and may not be readily available [11].

Iron deficiency (with or without anaemia) is common, particularly in female athletes, and can negatively affect athletic performance. Regular monitoring of iron status has been recommended in elite female athletes (particularly endurance athletes [12]), and it may also be worth checking the iron status of male athletes on entry to an elite programme [13].

Screening for other medical problems that could negatively affect exercise may also be indicated if there is a high prevalence of a particular condition in the population being considered, as long as it is easily diagnosed and treated.

9.5 Other Issues to Consider

In order to get the most out of your PPA, it is worth investing some time in planning well ahead of time. As mentioned earlier, engaging the whole of the management team in the planning process is invaluable when trying to implement any particular rehabilitation or injury prevention programme recommended following the PPA. Several questions need to be addressed.

9.5.1 What Is the Make-Up of the PPA?

There is no ‘one-size-fits-all’ PPA template that suits all situations that can be found in a text book. Many different factors need to be taken into consideration when designing a PPA template, but perhaps the most important is to first establish the goals of your PPA. Once these have been established, then a template can be tailored to the population being considered:

- Sport—take into account the injury epidemiology of handball—refer to the chapter on handball injury epidemiology (may be position-specific—e.g. ‘goalies elbow’).
- Gender—female players have a higher incidence of ACL injuries and are more prone to iron deficiency.
- Age—consider growth-plate-related issues in adolescent players.
- Level—consider any particular competition or travel-related medical requirements in elite teams.
- Geographical location—consider any local endemic diseases or medical problems, for example, it may be worth including a dental assessment as part of the PPA in areas where there is a high prevalence of gum and dental disease.

Ultimately, however, the contents of the PPA will be dictated by the available resources such as money, time available to assess players, numbers and experience of medical staff able to perform the screening as well as access to specialists.

9.5.2 When to Perform the PPA?

The PPA is traditionally done in the preseason period and is often the first time that medical staff get to meet new players. The preseason period is therefore the only time the whole squad for the forthcoming season can be assessed together.

However, there is also additional value in performing a more compact 'exit medical' at the end of the season to identify existing injury or illness problems and plan any off-season rehabilitation programmes or surgery.

9.5.3 Who Should Perform the PPA?

The PPA frequently involves the players seeing several members of the medical support and fitness staff for different sections of the PPA, although it is usually the team doctor that reviews all the results of the PPA and takes overall responsibility.

9.5.4 What Are the Medical Team Protocols?

Although seemingly outside the brief of this chapter, the preseason period is the time for the medical staff (including strength and conditioning/fitness staff) to establish medical protocols for the coming season, and reviewing these can often be included with the PPA planning session. The following are examples of issues that need to be considered:

- Reviewing the emergency action plan for medical emergencies (at home and away)
- AED access and maintenance schedule
- How and when to practise the emergency plan
- Prophylaxis and management of infectious disease outbreaks
- Health and recovery monitoring
- Supplement policy
- Establishing with coaching staff protocols around
- Assessment of injuries during matches (especially concussion) and communication with coaching staff
- How to ensure consistent communication between medical and coaching staff about injuries
- How post-injury return to play decisions are made

9.5.5 Injury/Illness Prevention Does Not Stop at the PPA

Although the PPA is often seen as an injury prevention tool, it should be remembered that injury causation is multifactorial and that many of the factors that may predispose to injury, such as training and playing load, quality of recovery (sleep, nutrition, hydration, stress) or playing surface, will vary over time. As such, injury prevention is not a one-off exercise, and some form of ongoing health monitoring of injury causation factors may help to identify when a player may be at increased risk of injury.

The primary goal of the PPA is to assess the current health status of the player. The make up of a PPA needs careful planning

Avoid the temptation to copy and paste a screening template from a book, if possible, involve the whole medical and management team in planning for the PPA.

First—Decide on the goals of the screening
Then—Tailor the contents of the assessment to:
The population being studied
The available resources

Have a clear plan for what to do with any abnormal results of screening tests.

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10

Medical Coverage of Major Competitions in Handball

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10.1 Introduction

Leading the planning, preparation and provision of medical services at an international elite sports event, such as a Handball European or World Championship, is a milestone and highlight in any sports physician's career. Being aware that the work environment at such events might differ considerably from one's day-to-day role and responsibilities is critical to success, as is the preparedness to learn and adapt.

Any physician, given the opportunity to lead the organisation and delivery of medical services at an international elite sports event, has to understand the framework in which they operate. The setting at these events poses challenges very different from a hospital or private practice environment. While requirements are not always clearly defined, expectations by all stakeholders regarding their access to and the quality of healthcare provided will generally be high. Apart from the need to comply with limited budgets, where medical services do not usually feature on top of the priorities list, their needs with regard to further resources and support will compete with those of many other parties and providers specific to the sport, the related International Federation (which may be the world governing body of the sport or a continental body) and their rules and regulations, the individual Local Organising Committee (LOC), national law and the local setting (Fig. 10.1).

There is a growing body of knowledge on medical service provision at mass events such as marathons, the overriding public health issues of large sports gatherings and how to deal with cardiac events and collapse in individual athletes. The International Olympic Committee provides comprehensive and detailed requirements for Olympic Games and also collects data quantifying and qualifying the eventual injury and illness profile as well as services delivered. Information and guidance on how to plan, prepare and organise medical services at the interface of the LOC and an International Federation is, however, still scarce [1].

Experience as a team physician who has participated at such events is always an advantage. Most essentially, however, are the ability to understand a multi-stakeholder setting, open-mindedness, flexibility, excellent communication skills and the willingness as well as the capacity to improvise and compromise—albeit never on the expense of the players or any other stakeholder's safety and health.

This chapter aims to outline the general characteristics of medical service delivery at sports events as well as the specifics of service provision in handball from a chief medical officer's perspective and based on the experience of the local

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Fig. 10.1 World Handball Championship 2015

medical team for the 2015 World Championship in Qatar to assist future providers in their planning and preparation.

10.2 Understanding the Framework of Medical Service Provision at International Elite Events

The local medical team in charge of delivering health services at an international elite event has to act within a complex framework of stakeholders that goes far beyond and at the same time directly influences the actual patient-provider relationship. It is important to comprehend the role, responsibilities, significance and influence of all these stakeholders to successfully navigate the different phases of medical service planning, organisation and implementation and establish optimal conditions for their delivery.

10.2.1 Local Organising Committee

The focus of any LOC has to be on serving the athletes and providing them with conditions to perform at their best. The LOC of a sports event is a temporary structure set up in due advance prior to an event to ensure that the organisation meets all the requirements of the related International Federation which owns the event. It usually consists of different functional areas that attend to specific circumscribed aspects of the event organisation.

With regard to medical services, it is critical for all medical staff to understand that their services and contribution are only one part of the LOC framework and have to work congruently with all the other **LOC functional areas**.

There are a number of functional areas within the LOC that are particularly important for the delivery of medical services:

- **Venues/site management**: for clinics, access, evacuation routes and provision of medical buggies (golf carts with space for stretchers and equipment).
- **Accommodation**: to facilitate setup of ‘hotel clinics’.
- **Accreditation**: the accreditation specifies access of the holder to predefined zones within each venue. The allocation of zone access appropriate for the respective function of medical staff is critical and needs to be ensured. There are extensive requirements for the identification of staff and often early deadlines.
- **Hospitality/protocol**: to be able to establish VIP medical rooms/clinics within or close to VIP lounges at venues and VIP hotel medical services.
- **Catering**: for provision of food and beverage to medical staff.

- **Transport**: to facilitate non-emergency transport/parking permits.
- **Security**: to ensure access of ambulances, golf carts and medical staff to patients for evacuations and emergencies, to secure and cordon off the location of an incident, etc.
- **Spectator services**: to coordinate medical services to spectators.

10.2.2 International Federations

At an international handball event, the related International Federation (e.g., the *International Handball Federation (IHF)* as the world governing body of the sport or the *European Handball Federation (EHF)* as the continental body) comes in as a further important counterpart whose regulations and expectations have to be identified and met. The extent to which International Federations have defined the exact requirements for medical services to all stakeholders at an event varies considerably. Some International Federations might display their requirements on their website, whereas others might only provide it to the LOC of a designated event. Ideally, these requirements, where existing, should be known to the LOC during the bidding for an event and be considered and addressed in the bidding documents.

After an event has been awarded, it improves efficiency and effectiveness in the planning and preparation when the LOC chief medical officer/medical director is able to communicate directly with the medical delegate or the chair of the medical commission of the related International Federation. This also helps to instil trust and confidence in the capabilities on-site and initiates a relationship that will be intensified during the event.

10.2.3 Visiting Medical Staff

The medical staff of the participating teams have their own specific level of experience, operation and requirements that need to be duly considered when designing services. In handball, the experience and requirements might vary considerably among teams.

At international elite events, the authority of the team physician/clinician in all medical matters related to their players has to be held in high regard by all LOC player medical staff. The LOC medical staff must only interfere upon specific request of the team physician/clinician, unless these are not able to attend to an incident involving any of their players.

10.2.4 Government

Any country will have specific requirements and laws applicable to mass gatherings. Further regulations might apply to immigration, port security, communicable disease monitoring and control and public health issues. Food security at hotels and official venues will need to follow official requirements. Specific rules applying to the import of medication and equipment as well as to licencing of visiting medical staff need to be identified, communicated and adhered to. The government might have also made commitments during the bid for the event that are relevant for medical service provision and that the medical team or LOC might be held accountable for by the International Federation.

10.2.5 Patients

Handball players are the primary potential patient group that need to be provided with high-quality sports medicine and other specialist services they can easily access at any time. At an international elite-level event, such as a Handball World Championship, there are several further stakeholder groups that require and expect high-quality and prompt medical care (very important persons (VIPs), team delegates, media, travelling fans, other spectators). These stakeholder groups are not necessarily within a sports physician's expertise and might not have been a part of their routine practice previously. The experience of these stakeholder groups, however, significantly shapes the public perception of the LOC and the host country, and every effort should be made to ensure their needs are met.

10.3 Providing Leadership

10.3.1 Building a LOC Medical Team

In order to provide for the needs of the various stakeholder groups, it is common for the LOC medical team to engage and assemble different service providers with specific expertise who might not have been working together previously. Mostly, there will be specific sports medicine and trauma experts for players, as well as general medical services and emergency and first aid services for spectators, media, workforce and others. These providers may come from different company cultures, each with their individual hierarchy, processes and work ethos. Some of them might offer their services at the event voluntarily, while others deliver them as part of their employment (Fig. 10.2).

The leadership of the different service providers involved and, in fact, every member of this diverse medical team needs to be aware that all services at the event can only be provided via an explicit team effort, with close collaboration and an open mind. This medical team needs to be carefully built and nurtured. It is important that everyone on the medical team can focus on and excel in their area of expertise while continuously communicating with, complementing and learning from the other team members.

It is critical to acknowledge and give importance to every single member of this team, regardless of their position, title or specialty. The medical leadership has to continuously show that they highly value each individual's contribution and consider them essential to achieve the overriding goal. In our experience, daily contact between the CMO and VMOs, as well as the CMO and medical coordinator visiting one venue each day of the competition to liaise with the medical personnel there, help foster an atmosphere of support and confidence.

10.3.2 Chief Medical Officer

Usually, a chief medical officer (CMO) or medical director will be appointed by the LOC to plan, coordinate, organise and lead the medical services. The ability to communicate and liaise with all other functional areas within the LOC, understand their needs and create an understanding of medical services on their part and discuss and achieve compromise starting in the planning phase is a critical quality required from any CMO who wants to suc-

Fig. 10.2 Venue medical team debrief

cessfully operate at a high-level competition (e.g. European or World Championship).

The CMO represents the highest medical authority and is responsible for coordinating and overseeing all medical providers and their services to players, match officials, delegates, volunteers, spectators and all other stakeholder groups. They should be well connected within the national/local healthcare setting and have the standing and authority to coordinate service delivery across institutional and geographical boundaries. It is advised to choose a person with an excellent reputation within the medical community, long-standing broad leadership experience with large multidisciplinary teams as a manager, high levels of competence and knowledge and ideally a deep understanding of the sport and the needs of all stakeholders. The CMO should be familiar with and highly regarded within the local healthcare system in order to be able to link the event services with all relevant providers, effectively and efficiently plan and draw from the available resources and ensure access to specific services when needed. Experience in major international events, whether as team physician/clinician or on the LOC side, should be a requirement.

The most critical task for the CMO is building their team. They will not only need peers to provide best care to all different stakeholders, but, importantly, they require efficient and effective administrative support.

The key tasks of the CMO include:

- To ensure multidisciplinary care of the highest international standards for players
- To recruit a medical team that meets the varied requirements of services to the different stakeholders
- To establish the medical facilities and infrastructure guaranteeing immediate access to care
- To integrate on-site care with the local and regional health services to provide for the needs of all stakeholders
- To implement clear, consistent, continuous and effective communication
- To build team spirit and foster a positive working environment for all medical staff

10.3.3 Medical Coordinator

In order to make sure that the medical service requirements are duly considered and coordinated with the other LOC functional areas in the planning and preparation phase, to meet deadlines and prepare requested updates and reports on the functional area medical services, develop workflows, assist with organisational charts, rosters, equipment and material lists, attend meetings and on-site inspections, develop contact lists and communication material, it is essential to establish a (full-time) medical coordinator position. Apart from the many administrative tasks that need to be attended to, a visible presence and permanent contact within the LOC is critical to give ‘medical’ the required weight and importance as a functional area.

The medical coordinator will also be highly valuable as a permanent contact point in the communication with the related International Federation, participating teams and all medical service providers involved. The sooner in the process the medical coordinator is able to establish this communication (ideally, as soon as all participating teams have been determined), the better the various needs can be addressed.

10.3.4 Venue Medical Officer

Ideally, at events with several venues, the CMO will be supported by venue medical officers who provide leadership to all medical staff at the individual venues and serve as the point of contact for the team physicians/clinicians in each venue. Choosing the most suitable personnel for these key positions is essential (Fig. 10.3).

These positions require a high degree of clinical knowledge and competence as well as leadership skills and experience in working with diverse, multispecialty groups. The ideal candidates should have a background of medical services delivery at sports events and possess extensive experience and judgment to plan and accomplish their goals. They should have a medical degree and a fellowship/specialisation in either sports medicine, sports surgery, emergency

Fig. 10.3 Medical services venue team

medicine, or a related area preferably, as well as leadership experience in a multidisciplinary team. Having knowledge of the sport will greatly assist them in their task. Managerial skills and a commitment to hard work regardless of official hours during the event are essential.

10.3.5 Medical Provider Meetings

These should be organised as often as needed prior to the event in order to create one team, communicate the plan for services and all organisational matters of relevance to the team, inform on accreditation and access procedures and share the clinical pathways, decision-making processes and reporting lines. A staff manual may be developed and distributed to all members of the team.

10.4 Communication

Communicating proactively and clearly with all involved parties, from the relevant functional areas of the LOC, all medical service providers and the visiting medical teams to the medical representatives of the related/associated Handball Federation is absolutely critical for successful delivery. Setting up a good and dependable communication network is key, with easily accessible personal, phone and online services as well as sufficient manpower to facilitate and channel the communication.

10.4.1 Provisional/Temporary Licencing and Medication Importation

When and where necessary, any needs for temporary licencing of visiting medical teams and medical representatives of the associated Handball Federation need to be communicated in due advance together with the exact conditions, the process for obtaining the licence and all required documents. The LOC should aim to facilitate the process with the relevant professional body in the country.

Any specific rules and laws applying to the importation of medication or medical equipment, the need for advance registration and/or declaration and the applicable customs procedures should also be communicated in time for the team physicians/clinicians to be able to prepare any necessary documents and lists.

10.4.2 Team Physician Meeting: Inform, Connect and Reassure

Team physician/clinician meetings prior to the start of a competition are a standard procedure at international sports events to inform visiting team physicians/clinicians on the services available to them, introduce them to the local medical team and facilities and provide them with important points of contact. Relevant information about the local medical services available in each venue are provided as well as close-by extended services (hospitals, clinics, imaging services, etc.), if necessary. This meeting is also the occasion to inform on any additional activities planned at an event, such as educational activities or research projects, where the collaboration of the team physician/clinician is required.

The planning and organisation of this meeting need to consider the arrival times of teams, training schedules and the timing of other relevant meetings related to the competition. It needs to be carefully coordinated with both the medical representative of the associated Handball Federation and the LOC competition, hospitality and logistics functional area.

The associated Handball Federation will usually provide a brief overview on the medical services and the doping control programme at this meeting. If planned, this is also the occasion for the injury and illness study group to present themselves and the project and establish contact with all team physicians/clinicians. When possible, it is advisable to contact the participating teams and team physicians/clinicians in advance, as early as possible (months) before the event, to address some of these issues and facilitate information exchange on special requirements and preparations.

10.4.3 Event Guide

A medical guide should be prepared and provided in advance for any visitor to the event. It should provide an overview of the environmental and health conditions, general health services in the host country, vaccination needs and medical services provided at the venues and at the hotels for players, delegates, media and spectators.

10.4.4 During the Event

10.4.4.1 Communication Services

The ability to quickly communicate information and decisions specific to medical service delivery is paramount to a successful provision. Medical staff will usually receive tetra radios which are programmed to a dedicated medical channel. A radio check should be performed each day before the commencement of duties. At a major international competition, a dispatcher will be employed to deploy local medical units and particularly ambulances.

10.4.4.2 Media Relations

For any communication with the media, the applicable rules of the associated Handball Federation and the LOC need to be established and strictly adhered to. No information or comments should be released to the media and reported by the media without prior information/approval of the responsible associated Handball Federation or LOC officials. This is usually coordinated between the CMO or medical coordinator and the event's media coordinator.

10.4.4.3 Daily Debriefs

These meetings at the end of each day are invaluable to ensure that relevant experiences and knowledge are shared, understood, applied and deployed rapidly. They also serve to strengthen the team and acknowledge staff contribution and performance.

10.5 Regulations for Handball World and European Championships

In handball, the world governing body of the sport is the *International Handball Federation (IHF)*. The *VI. List of Duties for Official IHF Competitions*, September 2007, can be accessed online and provides the following information in:

> Rule *3.5* Medical care/Doping tests [2]
>
> (a) Medical care
>
> 1. The organiser is responsible for the medical care in all playing venues.
> 2. The organiser should provide a medical doctor and paramedical personnel in all playing venues.
> 3. The doctor should be seated on the first row of the tribune behind the table. The doctor shall be introduced to a representative of the IHF

before each game. The medical facilities in the hall shall be shown to the representative of the IHF.

4. The doctor has to be assistance to:
   - the team physician in emergency cases (e.g. hospitalisation of a player)
   - spectators who need immediate medical treatment
   - IHF officials who need immediate medical treatment
5. The organiser shall provide the name of a designated hospital in all playing towns. This hospital has to be inspected beforehand.
6. The organiser shall provide medical service for the IHF referees and officials as for those teams which have no team physician.

For courtside medical teams, it is important to know the applicable rules for entering the court and attending to injured players. The *International Handball Federation (IHF)*, *Rules of the Game*, *Indoor Handball* (in place since 1st July 2016) defines the respective processes related under ***Rule 4***: **The Team, Substitutions, Equipment, Player Injuries, 4.11** [3].

The *European Handball Federation (EHF)* defines the following under Article 2. *Set-up guidelines for free space in the arena and competition technology* in their ***Set-up Guidelines for EHF Euro Event*** Halls [4]:

2.11. First-aid service for players

- The hall shall have a specially furnished room for the administration of first aid and other medical treatments to players.
- In international events, the presence of an ambulance vehicle staffed by a physician and nursing staff has to be ensured during the entire playing time as well as during the 30 minutes before the match. Appropriate parking with unobstructed access and exit has to be provided.
- It is important to keep routes leading outside short for quick evacuation.

2.12. First-aid service for spectators
In the hall, a separate first-aid room shall be provided for spectators, which must be properly marked.
Responsibility in this regard rests with the COC/LOC under the applicable Regulations.

The LOC medical team needs to be cognisant of any specific regulations or guidelines by the related Handball Federation's medical committee on the medical services required during a championship. It is important to establish contact early to ensure the LOC is cognisant of all the latest requirements to guide their planning.

10.6 Recommendations from Previous Major Handball Events

This section describes specific considerations regarding the organisation of the services at major handball events based on the experience with the last World and European Championships and provides some key performance data to guide future organisers in their planning and organisation.

It is important to note that great logistic variance may exist depending on the size of the host country, number of venues and distance between venues. In smaller countries with a small number of venues, they may even be located in or around one city in some instances. This may have the logistic advantage that all services to players could be provided by fewer, or even only one, hospital dedicated to the event, facilitating coordination and accessibility. This may be a specialised sports medicine institution or a general hospital with specialised departments. In any case, a general hospital(s) with a broad spectrum of specialties is always required as a back-up for a sports medicine provider in case of serious injury requiring advanced trauma and intensive care for players and to cover the needs of the other stakeholders.

In most host countries, there will be several host cities usually with one competition venue in each. As a consequence, medical service providers and hospitals have to be identified in all locations.

10.6.1 Key Objectives in the Medical Coverage of Major Events in Handball

To guarantee timely expert care at all competition and training venues, hotels and other whereabouts of stakeholders including:

- Ensuring that medical facilities at all sites are equipped to international standards
- Developing an infrastructure guaranteeing immediate access to medical services for all stakeholders
- Implementing close coordination with local authorities to ensure complete coverage
- Protecting privacy and confidentiality of all stakeholders at all times
- Assuring continuous and reliable communication along the defined lines of command
- Documenting all incidents at the event to establish the spectrum of injury and disease and inform future planning of medical services

For Players and Team Physicians/Clinicians:

- Optimal support of the work of the visiting medical teams
- Delivery of high-quality sports medicine services at competition and training venues
- Provision of medical services, nutrition and food services at each team hotel
- Immediate access to premium services for players at a specialised sports medicine hospital on a 24 h/day basis for treatment of any acute injury
- Dedicated access to the hospital for players with non-acute injury on an appointment basis
- Pathways to expedite player access to partner healthcare providers as required
- Providing comprehensive information on medical service provision to team physicians/clinicians

For Other Stakeholders:

- Medical services to spectators, media, VIPs and workforce at venues
- Medical services to VIPs and delegations at designated hotels
- Medical services at the main general hospital with priority access for VIPs
- Prepare a medical guide for all visitors to the Handball World Championship

Research and Education:

- To hold a two-day conference for all local and visiting medical staff prior to the event
- To support injury and illness prevention through the implementation of epidemiological and other observational studies
- To provide video analysis of all matches for injury monitoring, self-assessment and future injury prevention

10.6.2 Key Recommendations: Lessons Learned from Previous Major Handball Events

- **Players**: A players' medical room at each competition and training venue staffed with a nurse and physician is recommended. In addition, one to two dedicated ambulances at each match (one for training) should be assigned. A player medical room should also be considered at the team hotels; previous models employed one nurse permanently stationed at each and a floating physician. A designated sports medicine hospital with premium services delivered by a multidisciplinary specialist team and with high-level imaging facilities including X-ray, ultrasound, CT scan and MRI should function as the primary referral centre for all team physicians/clinicians who require assistance in treating their players. Clinical pathways need to be established for player incidents on the court during match and training and in the hotel, including the exact process for referrals.
- **Team physicians/clinicians**: Team physician/clinician information on all services should be provided to the related Handball Federation and distributed to the participating National Federations 3 months in advance (where possible), including specific information on importation of medication and temporary registration for team physicians/clinicians. A team physician meeting, ideally hosted at the sports medicine hospital, should be scheduled after arrival of teams prior to the event and familiarise them with the facilities. A handout with all direct contacts to access services 24/7 should be provided.

- **VIPs**: Many high-level sport and country representatives attend at elite events and will be assigned designated areas (VIP lounges). VIP clinics should be established at all competition venues adjacent to the VIP lounge with a dedicated ambulance and a VIP medical coordinator (depending on the size) attending to their needs as well as a VIP clinic at the VIP hotel. All VIPs need to have access to a general hospital where arrangements for priority services may be made in advance.
- **Main media centre**: A nurse or designated personnel should be stationed at the centre in order to assist media staff with minor issues and to direct them to the spectator clinic for major issues.
- **Spectators:** Spectator clinics should be set up on every concourse level at each venue and run by the local service providers. In large venues, where long distances may be needed to be covered, golf carts or other motorised mobilisation vehicles are recommended. Ambulances in sufficient number should be stationed at all venues as per the national standards. Referral to a general hospital has to be available as required (Fig. 10.4).
- **Event medical guide**: A guide for all visitors with all health-related information should be developed and distributed as part of the event guide. It should include general advice and weather and preventative recommendations (e.g. vaccinations, water safety) and describe the medical facilities and services available to all stakeholders.
- **Priority access to the designated general hospital:** Ensuring immediate consultation also in non-emergency cases for players and VIPs.
- **Match officials**: The medical care for all match officials should be facilitated at the players' medical rooms when at the venue. When outside the venue, the care for the officials could either be directed to the players' medical room at the venues, designated hotel clinics or the closest local clinic.
- **Injury and illness epidemiology surveillance**: A comprehensive injury and illness surveillance study of all players at the championship is recommended and should become an integral part of any major handball event. It may be coordinated through the medical or research sections of the related International Federation. For this purpose, a research team should be assembled and plan all the study logistics including a comprehensive manual for team physicians/clinicians. Information about the data collection/study should be presented at the team physician meeting prior to the event (wherever possible further in advance). Consent should be obtained from all participating play-

Fig. 10.4 Venue medical team

ers through their team physician/clinician. Those responsible for the study should provide proof of appropriate data storage and protection according to the highest international regulatory standards. Throughout the event, researchers need to collaborate closely with team physicians/clinicians to achieve optimal compliance and accurate data delivery. High-quality data allows for detailed injury analysis, epidemiologic registration and more effective injury prevention [5]. It may further be used to revisit clinical decision-making.

- **Handball sports medicine conference:** A pre-event medical conference is highly valuable to provide an overview and update of scientific and sports medicine aspects focusing on handball. All visiting medical teams and all medical service providers at the event should be invited as well as medical personnel from the related International Federation.

10.6.2.1 Venue Organisation for Players

The different competition venues should be organised in the same way, as conditions allow, with regard to the player medical team and their collaboration with other LOC functional areas. This facilitates orientation of all medical staff and their familiarity with the facilities and specific setup.

Medical Staff

All medical staff should be easily identified by their uniform. At each venue (stadium), the team should include:

Venue Medical Officer (VMO)

The VMO is responsible for coordinating and overseeing the emergency and general medical services to all stakeholder groups at the venue. The VMO also acts as the primary point of contact for the team physicians/clinicians during match play or training at the venue. He ensures that any needs of players (including transportation to the most appropriate facility) are met and assists in the assessment and treatment of players with acute injuries as required.

Courtside Staff

Paramedics and a physician should be positioned at the courtside. They may be supported by trained personnel to evacuate players off the field, if and when necessary and with the appropriate equipment. Courtside staff should have current Advanced Cardiac Life Support certificates.

The VMO and all player medical staff have to be provided with accreditation granting them default access to the field of play and the official areas, plus all other areas (Fig. 10.5).

Fig. 10.5 VMO team

Facilities

Player Medical Room

A fully equipped, dedicated player medical room should be situated in close proximity to the court and the locker rooms at each venue. The VMO should introduce the facility to all team physicians/clinicians and advise them to make themselves familiar with the location on the first day of playing or training at the venue. The room should be staffed on match days from at least 1 h before throw-off until 1 h after the final whistle and on training days from at least half an hour before training started until half an hour after its end.

Ambulance Services

It is recommended that two dedicated ambulances for players be made available and stationed close to the easiest evacuation path from the court and the player medical room. In case the player ambulance departs for transporting a player, the ambulance dispatcher should coordinate substitution as required.

Match Officials

The VMO should act as the first point of contact for match officials in case they have any health issues, except in situations where there was an acute incident on the court where the courtside staff would directly attend to them. In case more extensive examination or treatment should be needed, the player medical room would accommodate match officials. The pathway for assessment, treatment and referrals of players would in these cases be applied in the same way to match officials.

10.6.2.2 Hotel Services for Players

Team physicians/clinicians remain the first point of contact for players and any member of their national delegation at the hotels. In case they require assistance in providing the service needed or wish to refer or admit a patient (either player or delegation member), a dedicated player medical room should be set up at each team hotel.

The clinics should be staffed by a designated hotel care medical team with a nurse available on call 24/7. A contact number should be available for times when the clinic is not staffed physically. In addition, a 'floating' physician should be available on-call who may be responsible for several hotels in the same area. In case of an emergency, the physician/nurse should involve the local emergency services.

10.6.2.3 VIP Medical Services

Venues

Fully equipped, dedicated VIP clinics should be set up close to the VIP lounge at each venue wherever possible. The VIP medical room should be staffed on match days from 1 h before throw-off until 1 h after the final whistle (Fig. 10.6).

Service provision at the 2015 Men's Handball World Championship in numbers

88 Matches covered
507 hours of training covered
Venue teams worked about 12–18 hours/day from the beginning of the test events until the end of the championship
420 Medical staff (n) overall working at event:
  90 Physicians, **252** paramedics, **21** nurses, **32** operational managers, **5** other
  66 Sports medicine staff, **202** Qatar Red Crescent, **116** main general hospital staff
  24 Medical staff of national security forces
  12 Ministry of Health staff
Facilities
7 Hotel clinics (**5** player medical rooms, **2** VIP clinics), **1** referee massage room with two beds
23 Clinics (n) at venues (**3** players, **6** VIPs, **9** spectators, **5** workforce)

1090 Medical encounters total
1044 Medical encounters at venues
  6 Players **9** VIPs **141** spectators 888 workforce
46 Medical encounters at hotels
  9 Players **37** VIPs and delegates

3 Players referred to main general hospital (concussion, blunt abdominal trauma, razor blade cut)
Player medical encounters at sports medicine hospital:
50 Players in outpatient department
35 Requiring imaging
Services to officials
65 Referee recovery sessions provided (32.5 h)
Transport on match days
14 Ambulances overall at each venue and in perimeter
  4 Golf carts
  1 Mobile unit clinic

10.7 Summary

Providing medical services at an international elite event such as Handball European and World Championship is an important responsibility and invaluable experience for all staff involved. Becoming familiar with and understanding the framework in which these services need to be delivered is critical to success. Planning is essential and needs to start in due advance and in collaboration with all stakeholders at the event. Medical leadership needs to be open-minded, flexible, prepared to adopt as well as improvise in their quest for maximum protection of player health and safety and possess excellent communication skills. A strong and supportive administrative staff is important, knowledgeable of event organisation and experienced in dealing with an international stakeholder audience.

Since the knowledge on medical and performance matters in elite handball is still rather limited, it would be important to the sport to conduct video analysis and injury/illness epidemiology surveillance at future major handball events. Holding a medical conference prior to the event is an excellent opportunity to share the existing knowledge, update medical staff on new insights and create an education and research network.

Take home message: For any sports event, the focus of the Local Organising Committee (LOC) is on providing athletes with conditions to perform at their best. Medical services, albeit important, play only one part in achieving this goal and have to fit into the LOC framework. Medical leadership needs to be open-minded, flexible and prepared to adopt and improvise in their quest for maximum protection of athlete health and safety.

10.7.1 Suggested Checklist for the Organisation of Medical Services at Handball Events

The below checklist depends on the size and level of an event but should include:

Fig. 10.6 Memories of a successful service delivery

- Chief medical officer appointed 2 years in advance.
- Identify key information: number of players competing, VIPs, media, spectators, workforce; location and number of all training and competition venues; arrival and leave schedule of participants; any defined requirements for medical services by IHF/LOC.
- Inspect medical facilities at venues in due advance/during construction of new venues.
- Define all infrastructure, equipment and staff needs shortly thereafter.
- Develop budget considering all of the above.
- Establish an organisational chart with clear reporting lines 1 year in advance.
- Clearly define written job descriptions for all medical staff.
- Key staff appointed strictly as per their qualification and experience.
- Liaise with the related Handball Federation and LOC of event early on.
- Contact other contracted healthcare providers to define their services, target groups and needs.
- Establish any temporary licencing needs and medication importation for visiting medical teams.
- Closely liaise and communicate with other LOC functional areas starting during the planning phase to promote understanding of each other's responsibilities and needs.
- Accreditation and access areas adequate for all medical staff to be defined within the deadline of that functional area.
- Define communication devices, establish separate radio channel to connect all medical staff throughout the event and identify required shared channels.
- Staff rosters finalised in due advance to allow for planning by all service providers.
- Order material and equipment for venue clinics as early as needed within your operational setting.
- Clinical pathways defined and distributed at least 2 weeks prior to the event.
- Define criteria and rules of communication to protect confidentiality of patient data.
- Electronic recording system for all medical encounters.
- Enter player data into medical record database prior to event whenever possible.
- Make extensive use of test event(s) for venue familiarisation and procedure testing.
- Mock drills with predefined scenarios starting with test event.
- Plan for and compile all information for team physician meeting prior to kick-off.
- Provide general health and medical service information to all stakeholders through LOC.

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Part III

Handball Injuries

Handball Injuries: Epidemiology and Injury Characterization: Part 1

11

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11.1 Introduction

Handball is played in 199 countries by over 20 million players worldwide in over 800,000 teams [1]. Since modern indoor handball has been introduced in the mid-1950s, it has been in continuous development and even more so in the past two decades with pronounced changes such as increased players' speed, strength, technique, and as a consequence adaptive changes in tactics and rules of the game over the years. Being a contact sport, handball is characterized by intense body contact, frequent intermittent running and pace changes, demanding one-on-one situations, and quick direction changes in combination with challenging technique and coordination elements such as catching, throwing, passing, and dribbling.

Since unlike basketball, handball players are allowed an unlimited number of fouls, which, within the game's rules, are considered good defense and aim to disrupt the attacking team's rhythm. It is common that "aggressive" contact is often used not only to stop the opponent (Fig. 11.1) but also to intimidate opponents from approaching the goal. Therefore, the referee has an important task taking care of the player's health by keeping the game fair and appropriately sanctioning brutal play.

Earlier studies have reported that contact-related injuries represent between 40 and 84% of the total number of injuries [2, 3].

Matches are played year round at the professional-level and the top-level players, in addition to their club activity, and are usually engaged in activity with a national team as well.

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Fig. 11.1 Contact commonly seen in handball in an attempt to stop a player trying to shoot (Photos courtesy of Lothar Gudat. Used with permission)

Combining national and international competitions with both their club (national and continental competitions) and national team, elite players can play well over 70 matches a year. World championships and continental championships are played every other year (consecutive years), and every 4 years, there is also a handball tournament as part of the Olympic Games. The physiologic loads that each player is exposed to vary depending on their playing level and the total number of players in their teams, however, are considered high, and there is only a short time to rest during major competitions where the top teams may play eight matches in approximately 2 weeks, such as during the European championships.

The purpose of this chapter is to review the injury incidence in the various populations playing handball. Match-related aspects will be discussed for injury mechanisms, injury time, and on-court position. Knowledge and understanding of the etiology, as well as the incidence of handball injuries, may be useful to increase awareness, recognize the risk factors for injuries, incorporate prevention strategies, and proper treatment. This chapter aims to create a concise knowledge base and provide better instruments for the medical personnel in handball to face these challenges.

11.2 Epidemiology

Injuries are common in handball as in other team ball sports, such as football and basketball [2–10]. The potential for injury in handball is related to its dynamic character and the less restrictive rules in terms of physical contact when compared with basketball, for example. There are many studies on handball, but there is a lack of knowledge concerning men's handball and especially at the elite level. Several studies have been performed evaluating injuries at the top international level for men in the Olympic Games [11–14], world championships [15, 16], African Clubs Championships [17], and Asian Handball Championships [18]. These studies represent the highest performance level; however, many other studies and data exist in handball, involving different age groups, gender comparisons, and in different levels of play. One of the challenges in assessing the true incidence and risk of injury in handball stems from the differences in injury definition in the literature. The time-loss definition is used in most studies, but some investigators have included injuries that do not necessarily answer to the time-loss injuries criteria. Most studies in elite handball define an injury as "any physical complaint incurred during a match that received medical attention from the team physician regardless of the consequences with respect to absence from the match or training" [3, 13, 16, 19, 20]. Another common definition is "an event causing time-loss from at least one match or training session". A third commonly used definition is "all injuries which led either to a temporary stoppage of the match or to substitution of the injured player" [14, 17].

Injury severity has been assessed in handball based on the time-loss method. There is, however, lack of uniformity concerning the time-loss ranges recorded in various studies. Another major issue is presented as this method does not sufficiently address the issue of athletes competing with pain or limitation, despite an injury or illness. This issue is more relevant when it comes to overuse injuries, but not only. To address this issue, the Oslo Sports Trauma Research Center (OSTRC) Overuse Injury Questionnaire was introduced [21] and later modified to address illness as well, introducing the Oslo Sports Trauma Research Center (OSTRC) Questionnaire on Health Problems [22]. Although necessary, these additional methods make it difficult to compare various epidemiologic factors in more recent studies to previous ones; however, this evolution in data collection is important and could prove fruitful in the future if well adopted by researchers. An additional important aspect is that the injury-registration level and methods vary between studies. In some studies, injuries were registered from hospital records, large national surveys, and even insurance company records [2, 23–26]. Injury data collected from hospital records or insurance companies may cause a bias and probably present a larger number of more serious and more acute injuries, while minor injuries and overuse injuries can be missed using this method. Other issues could arise from differences in registration methods, with various studies using questionnaires and telephone or in-person interviews as registration methods. It is also important to notice whether the registration was performed prospectively or retrospectively. When it comes to epidemiologic studies, the registration method can affect the accuracy and reliability of the data.

In addition, in handball, no consensus statement in terms of data collection and classification for injury type and injured body region exist. The two most standard classifications are the Orchard Sports Injury Classification System (OSICS-10.1) [27] and Sports Medical Diagnostic Coding System (SMDCS) [28], which are used in football, rugby, and by the International Olympic Committee [12, 13, 19, 29]. Both systems use a division into 17 (SMDCS) or 18 (OSICS-10.1) body regions, respectively.

Such a consensus is necessary in order to create a uniform method of injury and illness data collection in handball, compare data from various studies, enable identification of risk factors and populations at risk, and ultimately design well-targeted injury prevention strategies.

11.2.1 Injuries in Handball Vs. Other Sports

Few studies have compared handball injury rates with other sports. In a population of school children, handball-related injuries were less frequent than volleyball (4.3 vs. 6.7 injuries per 1000 training hours) and were also less than match injuries in basketball (14 vs. 23 injuries per 1000 match hours) [30]. Yde and Nielsen [31], found no significant difference in injury incidence between handball, soccer, and basketball in an adolescent population [31]. Another study using the same injury definition reported a similar match injury incidence in soccer (16.9 per 1000 match hours), but a much higher training injury incidence (7.6 per 1000 training hours) [32].

Recent epidemiologic data placed the sport of handball as one of the highest injury risk ball sports [25], and a recent study from Sweden even singled out handball as carrying the highest injury incidence rates after motorcycle/snowmobile sports with 63.4 injuries/1000 athletes years and ahead of all other sports [23].

11.2.2 Injury Severity

A major challenge when analyzing injury data in handball lies in the definition of injury severity. The most widely used classifications of injury severity in the handball literature are minor injury

(1–7 days absence), moderate injury (8–21 days absence), and major injury (>21 days). These ranges have not been uniform in different studies in handball, and therefore a closer comparison and analysis of injury severity between studies is difficult. While some studies do not include injuries without time-loss, some use different criteria [33], which are based on injury nature and duration, treatment type, time lost from sports, time lost from work, permanent damage, and costs. Langevoort et al. and Junge et al. based their data on estimations of absence duration after injuries and not actual follow-up. Table 11.1 presents the incidence of injuries causing an absence of >7 days (moderate and severe injuries) in elite-level major international competitions. Different ranges were used in the world championships in 2015, where injuries causing time-loss of 3 days to 4 weeks were grouped together (15.9%) as well as injuries >4 weeks (2.3%) [15].

The incidence of major injuries in handball ranges from 5 to 36%, and reinjuries are common [3, 10, 16, 34–37]. In one study, 20% of the players reported absence from handball for 4 weeks or more because of injury [3]. In the study by Langevoort et al., 5% of the injuries led to >1 week absences. Ankle, knee, and head injuries most frequently led to absences [16]. In addition, they reported that noncontact injuries caused longer absence from handball when compared with other contact injuries. In a study of youth players, Olsen et al. reported that 56% of the acute match injuries and 50% of acute training injuries were moderate (>8 days lost) or major (>21 days lost) injuries [35]. In an unpublished prospective study performed in Norway, Gundersen and Myklebust reported a 30% prevalence of major injuries with a time-loss of more than 28 days.

A recent study followed Brazilian elite handball players over a full season, reporting 31.7% of injuries resulting in >7 days of absence [38].

Full-season data from the first and second men's German leagues based on insurance company data from three consecutive seasons (2010–2013) revealed 10% of injuries were moderate (8–21 days), while 9.3% were major (>21 days) [39]. Data from the same insurance company during the 2015/2016 season presented an average of 52 injuries per team per season. The data also revealed that every player missed on average (cumulative) 30 days per season due to injuries [25]. Mean costs for medical treatment and rehabilitation were 1.320 € per injury in the 2015/2016 season. This added up to an annual burden ranging from 2 to 3 million € in the German first and second men's leagues. It is important to note that these insurance assessments are performed 3 months following the end of the season, and therefore real costs are expected to be even higher as some injuries may require longer than 3 months post season to resolve.

11.2.3 Adults

11.2.3.1 Longitudinal/Full-Seasons Studies

At the senior/adult level, the incidence of time-loss injuries in prospective studies has been esti-

Table 11.1 Duration of absence in elite-level competition >7 days

	Male						Female						
	2001 WC	2003 WC	2004 OG	2008 EC	2010 EC	2012 OG	2012 OG	2002 EC	2003 WC	2004 OG	2008 EC	2010 EC	2012 OG
Players (*n*)	160	160	87			178	178	96	160	66			171
All injuries	96	110	49	47	45	31	31	52	106	65	53	85	45
>7 days	4 (5%)	6 (7%)	4 (9%)	10 (21.3%)	7 (15.5%)	6 (3.4%)	6 (3.4%)	3 (6%)	4 (4%)	2 (4%)	7 (13.2%)	12 (14.6%)	10 (5.8%)

WC world championships, *EC* European championships, *OG* Olympic Games
Data based on Langevoort [16], Holdhaus [49–52], and Bere

mated to be 11.2–14.3 per 1000 exposure hours in matches and 0.6–2.4 in training [3, 36, 37]. In a retrospective study of 288 male players in Denmark (division 1–3), Jorgensen reported an overall rate of 8.3 injuries per 1000 h [5].

Moller et al. evaluated 171 senior players out of 517 elite-level players in various age groups in Denmark over 31 weeks [40]. They reported a match injury incidence of 23.5 per 1000 match hours, which is much higher than the previously reported incidence.

Data from the Icelandic top 2 male divisions (109 players) revealed 86 time-loss injuries, of which 62% were acute and 38% were overuse injuries. The incidence of acute injuries was 15.0 injuries/1000 h during matches and 1.1 injuries/1000 h of training [41].

Giroto et al. followed 339 Brazilian men and women elite handball players during a full season. In total, 312 injuries were reported by 201 athletes. The injury incidence rate during training was 3.7/1000 h, and during matches it was 20.3/1000 matches.

Recent injury data from Germany focusing on all professional male player teams of the German national first and second leagues (Bundesleagues) was analyzed [25]. Data was collected from an insurance company database as all the players in the highest divisions in Germany have their mandatory trauma insurance in the same insurance company—the largest statutory accident insurance in Germany (VBG—Verwaltungs-Berufsgenossenschaft). Injury data of 750 players in the 2015–2016 season was analyzed revealing a total of 7200 injuries, presenting an incidence of 77.7/1000 h in regular league matches (77.8/1000 h in the first Bundesleague; 81.1/1000 h in the second Bundesleague). Overall, 79.7% of the players in both leagues sustained an injury (83.2% in the first Bundesleague; 75.5% in the second Bundesleague). An average of 52 injuries per team per season was recorded. The overall number of injuries per player was 2.7 per season (2.7 in both leagues). This means that nearly 80% of all handball players, who played at least once for their club, suffered an injury in the 2015/2016 season. As previously mentioned, every player missed on average (cumulative) 30 days per season due to injuries [25].

11.2.3.2 Major Competitions

Langevoort et al. followed male and female elite-level players during major international tournaments (2002 women's European championship, 2003 women's World Cup, 2001 and 2003 men's World Cup, 2004 Olympics—men and women) and recorded 478 medical attention injuries (regardless of consequences). The competition injury rate was 89–129 injuries per 1000 match hours for males and 84–145/1000 match hours for females [16]. For comparison, Ekstrand et al. studied highest level of professional football play (the UEFA injury study) and reported that the acute injury incidence was 27.5 injuries/1000 match hours [42].

In the Langevoort study, the injury incidence per match per player was 1.2 for males and 2.0 for females [16]. When looking just at time-loss injuries, the rates were 31–40/1000 h for males and 13–36/1000 h for females (0.6 and 0.5 injuries per match per player for males and females, respectively). Overall, reports on injury prevalence in major competitions range between 17.4 and 27.1%. Time-loss injuries constitute between 13.4 and 40% of all injuries in major competitions. For the 2008 Summer Olympics in Beijing, Junge et al. defined injury as any musculoskeletal complaint that received medical attention regardless of the consequences (i.e., any absence) [12]. There were 58 medical attention (17.4%) injuries among the 334 handball players (male and female). They recorded 13.4% time-loss injuries with a predominance of match injuries (92.6%). Engebretsen et al. [11] used the same definitions for the 2012 Olympics. They recorded a total of 76 medical attention injuries (21.8%) among 349 players (male and female) and 13.8% time-loss injuries with a predominance of match injuries (75.3%). Data from the 2015 Men's Handball World Championships in Qatar (24 teams; 384 players) revealed 27.1% of the players were injured, and of the 132 injuries reported, 40% were time-loss injuries out of which 15.9% caused 3–28 days of time-loss and 2.3% caused >4 weeks' time-loss. The total incidence of match injuries was 104.5 per 1000 player hours (85.9–123.0) in total and 50.5 (37.6–63.4) for time-loss injuries, corresponding to 1.4 and 0.7 injuries per match, respectively [15].

Table 11.2 summarizes the injury rates from men's elite-level major international competitions.

Asembo and Wekesa followed the East and Central Africa Senior Clubs Championship in 1995, reporting an average incidence of 2.74 injuries/match [17]. They also reported an incidence of 0.9 injuries/player during the 19 matches played. Leidinger et al. analyzed injuries that required medical attention during a 5-year period (1981–1986) in German senior players [43]. They found that 96% of the players at the highest performance level (Bundesliga) were injured each year. Piry et al. [18] retrospectively evaluated the incidence of injuries during the 2008 Asian Handball Championships. They used the time-loss injury definitions but recorded non-time-loss injuries as well. They reported an incidence of 20.7 injuries per 1000 h of competition and 0.96 injuries per 1000 h of training. As expected, acute injuries (82.5%) were significantly more common than chronic injuries (17.5%). 15.9% of the injuries were severe (>21 days of absence from training and competition), while 20.6% were moderate (8–21 days of absence from training and competition) and 38.1% were minor injuries (1–7 days of absence from training and competition). The remaining 25.4% did not require absence from training and competition.

11.2.4 Youth/Adolescents

Earlier studies focusing on injury rates in young handball players have suggested similar rates to adults, with estimations ranging between 8.9 and 14 injuries/1000 match hours and 1.7–4.3 injuries/1000 training hours [3, 30]. Nielsen and Yde prospectively followed young handball players (7–18 years) in a single sports club in Denmark reporting an overall match injury incidence of 10 injuries/1000 match hours (11/1000 match hours in girls and 9/1000 match hours in boys) [3]. Using insurance records, De Loes et al. reported lower injury risks in adolescents (and similar between boys and girls) with 0.7 injury per 1000 playing hours [24]. Wedderkopp et al. evaluated the total incidence of injuries in Danish handball, not just time-loss injuries. They first conducted a retrospective study that showed young female players (16–18 years) have the highest injury incidence with up to 41 injuries/1000 match hours [9]. In their subsequent prospective study [10], the incidence in the control group (the same players from the previous retrospective study) was 23 injuries/1000 match hours. However, these studies cannot be directly compared with the other existing studies, as time-loss injuries were not reported separately. Wedderkoop et al. later conducted another retrospective study in a population of 163 young female (ages 14–16 years) players, over 1 season, reporting a rate of 52 injuries/1000 match hours [37].

In a prospective study in Norway, Olsen et al. followed 428 players (aged 15–18 years) in 25 female and 9 male teams. They recorded all injuries (not only time-loss ones) and found a match injury rate of 8.3 injuries/1000 h in males and 10.4 injuries/1000 h in females; training injury rates were 0.6 injuries/1000 h and 1.0 injuries/1000 h, respectively [35]. In a randomized controlled trial of an injury prevention program, Olsen et al. studied 1837 players aged 15–17 (120 teams) and recorded 298 injuries. The control group (male and female combined) showed a rate of 10.3 injuries/1000 h during matches and 0.6 injuries/1000 h during training [44]. Reckling et al. evaluated 100 German juvenile players (50 male and 50 females), reporting 130 injuries in 73 players [8].

In a case-control study conducted in the Netherlands among 642 players, trying to characterize handball injuries distribution, players >20 years of age were shown to have a significantly greater risk of injury than players <20 years of age (odds ratio = 1.9) [45].

A similar trend was shown in a more recent cohort study by Moller et al. who followed 517 male and female elite handball players (age groups under U-16, U-18, and senior) in

Table 11.2 Injury rates from men and women elite-level international competitions

	Male							Female					
Anatomic location	WC 2001 (men)	WC 2003 (men)	Olympics 2004 (men)	Euro 2008 (men)	Euro 2010 (men)	WC 2015 (men)	Avg. (%)	Euro 2002 (women)	WC 2003 (women)	Olympics 2004 (women)	Euro 2008 (women)	Euro 2010 (women)	Avg. (%)
Head and neck	11 (11.9%)	30 (28.3%)	15 (31.2%)	3 (6.4%)	11 (24.4%)	18 (13.7%)	19.3%	15 (30%)	30 (30.6%)	23 (36.5%)	13 (24.6%)	19 (22.3%)	28.8%
Shoulder, arm, and elbow	13 (14%)	10 (9.4%)	6 (12.5%)	5 (10.6%)	5 (11.1%)	12 (9.1%)	11.1%	13 (14%)	10 (9.4%)	6 (12.5%)	6 (11.3%)	10 (11.7%)	11.8%
Hand and finger	8 (8.6%)	10 (9.4%)	4 (8.3%)	11 (23.4%)	8 (17.8%)	10 (7.6%)	12.5%	8 (8.6%)	10 (9.4%)	4 (8.3%)	9 (17%)	6 (7.3%)	10.1%
Trunk	16 (17.3%)	14 (13.2%)	5 (10.4%)	3 (6.4%)	2 (4.4%)	15 (11.4%)	10.5%	4 (8%)	20 (20.4%)	12 (19%)	6 (11.3%)	19 (22.3%)	16.2%
Legs (muscles)	13 (14%)	1 (1%)	3 (6.2%)	10 (21.3%)	14 (31.1%)	8 (6%)	13.2%	3 (6%)	3 (3%)	3 (4.7%)	11 (20.8%)	15 (17.5%)	10.4%
Knee	*15 (16.3%)*	*15 (14.1%)*	*5 (10.4%)*	*6 (12.8%)*	2 (4.4%)	15 (11.4%)	11.5%	*5 (10%)*	*12 (12.2%)*	*10 (15.8%)*	4 (7.5%)	6 (7%)	10.5%
Foot and ankle	*9 (9.7%)*	*17 (16%)*	*8 (16.6%)*	*6 (12.8%)*	3 (6.8%)	28 (21.2%)	10.3%	*7 (14%)*	*15 (15.3%)*	*5 (7.9%)*	4 (7.5%)	10 (12%)	11.3%
Total	92 (100%)	106 (100%)	48 (100%)	47 (100%)	45 (100%)	132 (100%)		50 (100%)	98 (100%)	63 (100%)	53 (100%)	85 (100%)	

WC world championships, *EC* European championships
Data based on Langevoort [16] and Holdhaus [49–52]

Denmark. Data was collected through a web survey establishing injury history, demographics and sports experience, and weekly reports of time-loss injuries, and handball exposure for 31 weeks was reported by short message service text messaging (SMS) with high response rates (85–90%) [40]. They recorded 448 injuries, with 165 injuries (37%) being overuse injuries and 283 (63%) traumatic injuries. The injury incidence during match play was 23.5, 15.1, and 11.1 injuries per 1000 match hours among senior, u-18, and u-16 players, respectively. Traumatic injury rates were reported as 4.9, 3.7, and 3.3 injuries per 1000 match hours among senior, u-18, and u-16 players, respectively. Overuse injury rates were 2.2, 2.1, and 2.7 injuries per 1000 match hours among senior, u-18, and u-16 players, respectively. U-18 male players had an overall 1.76 times higher risk of injury compared to females. Having had two or more previous injuries causing absence from handball >4 weeks increased the risk of new injury in the u-16 group (IRR, 1.79–2.23). Another, more recent study by the same group using a similar data collection method looked at 679 elite youth handball players (14–18 years) and evaluated the association between shoulder injury and handball load (training and competition hours) over 31 weeks [46]. They discovered that a large increase in weekly handball load increases the shoulder injury rate in this population. They also found 2.5 times higher shoulder injury incidence rate among this population than they previously reported (1.4 per 1000 playing hours compared to 0.6) [40].

Recent insurance registry data from Sweden suggested a slightly different trend when analyzing injury data in handball players according to age groups, revealing the highest proportion of injuries in the 15–19-year-old age group (41%), followed by the 10–14-year-old age group (21%) and the 20–24-year-old age group (20%) [23].

A recent study from Denmark, the Childhood Health, Activity, and Motor Performance School Study (CHAMPS-study DK), evaluated the effect of sports participation on children aged 6–13 [47]. They reported soccer and handball were most strongly linked to overuse injuries of the lower extremities in this population.

Achenbach et al. recently published the results of a randomized controlled trial studying the effect of an injury prevention program on adolescent handball players [48]. The study population included a total of 279 adolescent players: 168 players in the intervention group and 111 players in the control group. They reported an overall incidence of 1.85 injuries per 1000 h handball exposure (intervention group, 50 injuries/incidence, 1.90/1000 h; control group, 32 injuries/incidence, 1.78/1000 h). Knee injury was the second most frequent injury in adolescent team handball players after the ankle. Severe knee injuries occurred significantly more often in the control group (injury incidence 0.33/1000 h) than in the intervention group (injury incidence 0.04/1000 h) [48]. Table 11.3 summarizes the various studies on injury incidence in youth handball players.

11.2.5 Gender Differences

When attempting to compare male injury rates vs. females according to time-loss injuries studies, significant gender-based differences are found only at the national teams' level, as shown by Langevoort et al. [16] and Holdhaus [49–52] (Table 11.2). In other studies, minimal gender differences were found [3, 35]. Gender differences, however, are evident when it comes to ACL injuries in handball, where women have an incidence 3–5 times higher than men [53–58]. Figure 11.2a, b summarizes injury frequency based on data from elite-level international competitions.

In their cohort of 517 elite players (senior, U-18, U-16) from Denmark, Moller et al. reported gender-related significant differences only in the U-18 group where the incidence of match injuries was 17.2 per 1000 match hours for males and 13.0 per 1000 match hours for females (1.76 injury rate ratio) [40].

Table 11.3 Epidemiologic studies on incidence of handball injuries among adolescents

	Design	Country, period	Population	Injury definition	Players (n)/ injuries (n)	Injuries/1000 h		
						Match	Training	Total
Nielsen and Yde [3]	Prospective cohort	DEN 9/1985–5/1986	1 club, age 7–18 years	An incident occurring during a game and practice in the club causing the player to miss at least one game or practice session	M: 40/15 F: 54/22	F: 11.4	F: 2.2	
Backx et al. [30]	Longitudinal	NDL 11/1982–6/1983	Schoolchildren, 8–17 years, boys and girls	Any physical damage caused by an accident during physical education or in any sports activities outside of school, both organized and nonorganized	M+F	M+F: 14	M+F: 4.3	
De Loes [24]	Insurance records	SUI 1987–1989	From "youth and sports" 14–20 years	All acute injuries occurring during the activities in "youth and sports"	M: 30,876/1052 F: 10,357/371			M: 0.72 F: 0.76
Wedderkopp et al. [9]	Retrospective cohort	DEN 1994–1995	22 teams, females, all levels, 16–18 years	Any injury occurring during a scheduled game or practice and causing the player to either miss the next game or practice session or being unable to participate without considerable discomfort	F: 217/211	F: 40.7	F: 3.4	
Wedderkopp et al. [10]	RCT (of teams)	DEN 8/1995–5/1996	22 teams, females, all levels, 16–18 years	Any injury occurring during a scheduled game or practice and causing the player to either miss the next game or practice session or being unable to participate without considerable discomfort	F: 126/66	F: 23.4	F: 1.2	
Wedderkopp et al. [37]	Retrospective cohort	DEN 1997–1998	Female teams ($n = 41$), male teams ($n = 9$). 14–18 year	Any injury occurring during a Scheduled game or practice and causing the player to either miss the next game or practice session or being unable to participate without considerable discomfort	F: 163/[a] F: 321/48	F: 52 F: 10.4	F: 1.0	
Olsen et al. [35]	Prospective cohort	NOR 9/2001–3/2002	Female teams ($n = 25$), male teams ($n = 9$). 15–18 years	Any injury occurring during a scheduled match or training session, causing the player to require medical treatment or to miss at least part of the next match or training session	M: 107/13 F: 321/48	M: 8.3 F: 10.4	M. 0.6 F: 1.0	
Olsen et al. [44]	RCT	NOR 9/2002–4/2003	120 teams, male and female, 15–17 years	Any injury occurring during a scheduled match or training session, causing the player to require medical treatment or to miss at least part of the next match or training session	M/F: 1837/298	IG: 4.7 Cg: 10.3	IG: 0.4 Cg: 0.6	
Møller et al. [40]	Prospective cohort	DEN 2010–2011	52 clubs, 517 players in 3 groups: u-16 ($n = 194$); u-18 ($n = 152$); and senior ($n = 171$)	Any physical complaint sustained by a player that results from a handball match or handball training causing the player to Miss part of or rest of the match or training session	u-16: 194/148 u-18: 152/117 Senior: 171/183	u-16: u-18: Senior:		

M males, *F* females, *RCT* randomized controlled trial, *DEN* Denmark, *NDR* Netherlands, *SUI* Switzerland, *NOR* Norway

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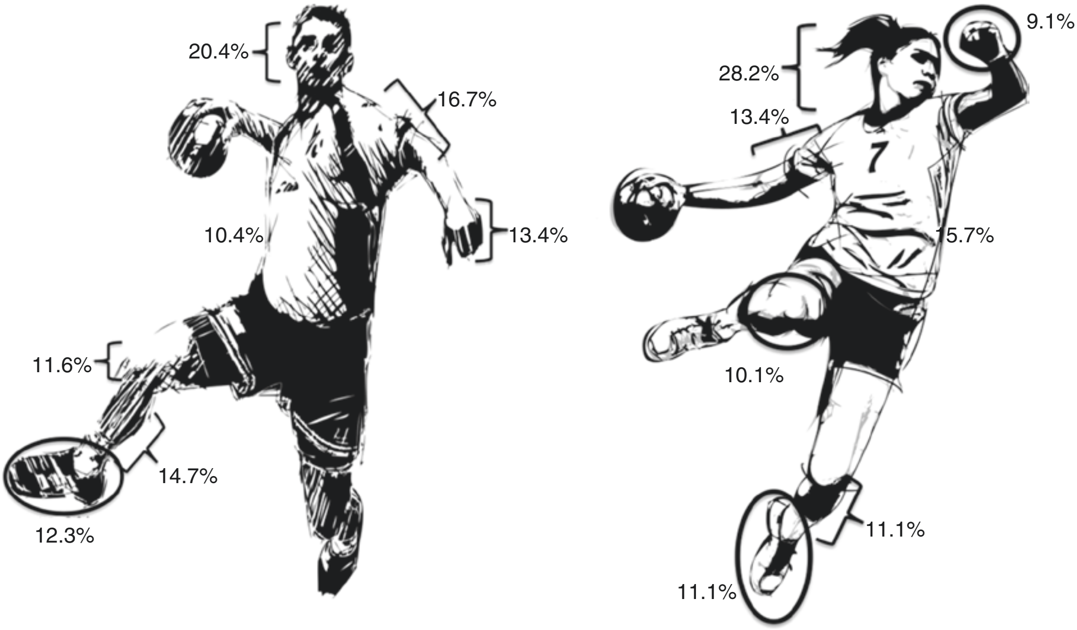

Fig. 11.2 (**a**, **b**) Injury frequency in males (**a**) and females (**b**) based on data from elite-level international competitions used with permission from Laver L. and Myklebust G. Handball Injuries: Epidemiology and Injury Characterization. In: Doral MN, Karlsson J, editors. Sports Injuries. Springer-Verlag Berlin Heidelberg; 2015

In a study on 339 Brazilian elite handball players over a full season (183 women; 156 men) out of a total 312 injuries, 176 were sustained by women (99 training injuries; 77 match injuries) compared to 136 by men (63 training injuries; 73 match injuries). Injury incidence in women was calculated as 17.9/1000 h for matches and 4.1/1000 h for training injuries, compared to 23.5/1000 h for matches and 3.2/1000 h injuries in men [38].

Aman et al. looked at insurance company data in Sweden between 2006 and 2013 and reported an incidence of 52.5/1000 athlete years in females vs. 46.5/1000 athlete years in males. When analyzing injuries causing permanent disability, the incidence was 6.9/1000 athlete years for females and 4.5/1000 athlete years for males [59].

11.3 Illness

There is a clear lack of information with regards to illness in handball. The only reports in the literature are from major competitions. The first report on illnesses among handball players came from the 2012 Olympics [11] where 7% of Olympic handball players were affected during the event. A more detailed report of illness rates in handball was performed during the 2015 World Championships [15]. In total, 10.9% of the players were affected by an illness during the event which resulted in subsequent absence from training and/or match play in two-thirds of cases. Of the 42 cases recorded, 31 (73.8%) were reported as respiratory tract infection. There is a clear need for further data on illness rates in handball players, and this should be one of the focus in future surveillance studies in handball. Understanding the epidemiology and extent of this problem in handball could help develop a systematic approach to illness prevention. This could potentially help reduce the extent of the problem by means of implementing preventive measures, such as general guidelines on illness prevention, screening, a vaccination program when applicable, and more specific measures to minimize infection risk where necessary.

11.4 Summary

One of the main challenges when analyzing handball epidemiologic studies stems from the definition of injury, which varies between studies and therefore presents difficulties when attempting to identify injury patterns and risk factors.

It is difficult to compare various epidemiologic studies in handball as many report data from major competitions which represent a "snapshot," although intense, in an elite handball player's season; however, neither represent the true nature of the loads and risks players are exposed to, nor it represents the majority of players. Very few studies have followed players over several consecutive seasons, which is a relevant strategy to characterize injuries and potential risk factors.

It is however evident that the sport of handball is one of the highest injury risk sports among Olympic sports. Using an injury incidence of 108 injuries/1000 match hours like Langevoort et al., this leads to 56 injuries in matches per team a year. These are high values, and even though the majority of these injuries are not major injuries and only 25% of all match injuries result in any time-loss, they accentuate the need to find and implement strategies to prevent and reduce the injury rates, as well as a good and continuous medical coverage for handball teams. Recent data by Luig et al. indicating not only high injury rates at the elite level but also a high proportion of players sustaining injuries (4/5 players) as well as the long layoff per player suggest that the economic burden of these injuries is higher than previously perceived [25].

New long-term prospective epidemiologic studies and data are in demand in handball, especially with the rapid evolution of the game and the high intensity and match density the players are subjected to at the competitive level.

It is evident that a consensus statement on injury and illness data collection in handball is necessary in order to create a uniform method of data acquisition and reporting, compare data from various studies, enable identification of risk factors and populations at risk, and ultimately design targeted injury prevention strategies.

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12 Handball Injuries: Epidemiology and Injury Characterization: Part 2

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12.1 Introduction

The specific features that differentiate handball from other sports also contribute to specific and typical injury patterns and distribution in the sport. Match intensity, players' positions, the contact nature of the sport, the intense and dynamic nature of each match, the dominant overhead throwing aspect of the sport, as well as the frequent pivoting movements—all these and more have an effect on *HOW* injuries occur in handball, *WHERE* do they occur, *WHEN* do they occur, and to *WHOM* do they occur.

When looking at anatomic distribution of injuries, it is evident from existing epidemiological reports that injuries to the lower extremities are very common in handball, and although several authors found an equal distribution between upper and lower extremity injuries [1–3], most studies show that most acute injuries in handball involve the lower extremities, regardless of age and gender [3–10]. This is the case when looking at injuries at the elite international level as well [11]. The most frequent injuries reported in handball involve the ankle (8–45%), while the most severe injuries involve the knee (7–27%) causing the longest absence from sport [3, 7] and accounting for most insurance-related costs [12]. A few elements distinguish handball from other team ball sports and could help explain the high incidence of ankle injuries. The amount of jumping involved in the game is significant at both ends of the court, and the most common jumping technique in handball is a single leg jump with the majority of players landing on a single leg, leading to high propulsive and impact loads on one

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Fig. 12.1 Ankle injury following an off-balance landing

leg. The most unpredictable factor in handball is the extensive amount of contact allowed, in comparison to, soccer and basketball for example. Even when the contact is sanctioned, many defensive players will risk contact for the price of being punished or sanctioned (unlike basketball, the number of fouls in handball is not counted or accumulated). Therefore, a handball player, while attempting to shoot the ball, will very often encounter contact while both legs are in the air, where even slight contact might tilt the player's balance, increasing the risk of an off-balance landing (Fig. 12.1).

It is therefore crucial to understand each of the sports' unique features in order to understand the epidemiology and in order to be able to derive constructive observations and conclusions.

The purpose of this chapter is to explore the injury distribution in handball through some of the specific aspects of the game.

12.1.1 Match Vs. Training Injuries

As in many other ball sports, match play intensity and contact are substantially increased compared to training in handball. It therefore does not come as a surprise that match injury incidence is significantly higher than training injury incidence [13–17], which is reflected by a high number of injuries caused by the opponent. This is accentuated in the highest-level competitions such as Olympic tournaments and European and world championships with match injuries comprising between 75.3 and 92.6% of injuries while training injuries comprising only between 7.4 and 24.7% of injuries [18–20]. The main reason for this pronounced difference in match and training injury proportions in major competitions is the high ratio of matches to training sessions, which is substantially different from the regular/full season.

A similar match injury to training injury ratio is also evident in young and adolescent players' populations as well with no significant gender differences apparent [11]. Significant differences between match and training injury incidence were also found recently by Piry et al. with 20.7 injuries per 1000 h of competition vs. 0.96 injuries per 1000 h of training [21]. Higher training injury incidence has been shown in lower level of play groups [7], a finding compatible with soccer player populations as shown by Ekstrand et al. [15], who noted a reduction of injuries with increasing training hours. This is attributed to improved coordination and skill, better oxygen uptake, and improved strength.

Looking at data originating from longitudinal/full season studies, the picture is different than the one evident in major competitions. While the incidence of match injuries is still substantially higher than the training injury incidence, the proportion of training injuries is much higher compared to major competitions. This is due to the "normal" ratio of training vs. match exposure during the season, with much more training sessions compared to the major competition scenario. Match injury incidence was significantly higher than training injury incidence in all age groups in a cohort of 517 elite-level players from Denmark, while the injury proportion in training was higher [22]. Another recent cohort of 339 Brazilian elite handball players demonstrated a match injury incidence rate of 20.3/1000 matches compared to 3.7/1000 h of training [23]. A study on 216 Greek male handball players of different levels showed a different pattern as at the lower level, the majority of injuries were reported during matches, whereas at the higher divisions, no difference was found between the percentage of injuries during a match or during training [24]. A similar pattern was observed by Luig et al. in the first and second men's German leagues over the 2014–2015 and 2015–2016 sea-

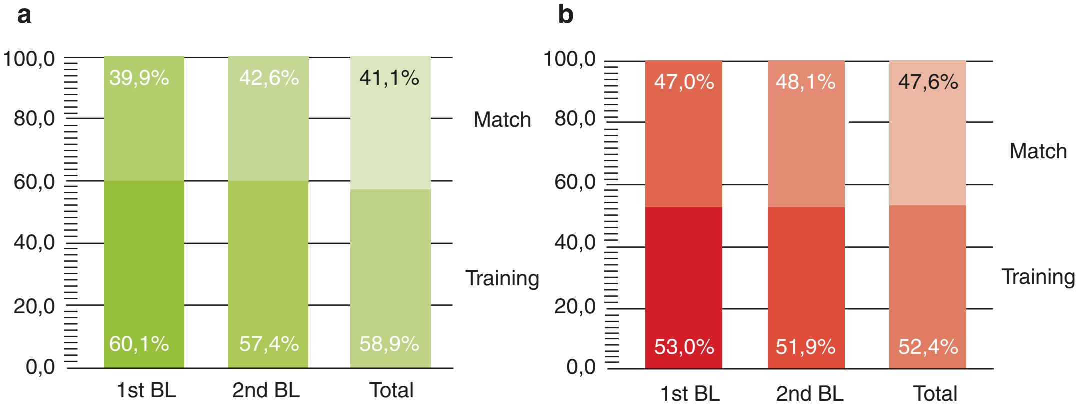

Fig. 12.2 Proportion of match vs. training injuries in the first and second German Bundesleagues (BL) over the 2014–2015 (**a**) and 2015–2016 seasons (**b**) Modified from [12, 25]. Used with permission

son based on insurance registry data [12, 25]. Figure 12.2a, b shows the injury proportion (%) between training and match injuries in the 2014–2015 and 2015–2016 seasons in the highest two divisions in Germany, showing a higher proportion of injuries occur during training (to distinguish from the incidence, which is higher in matches).

Fact Box
Match injuries incidence in handball is higher than training injuries.

12.1.2 Injuries According to Player Position

When analyzing injury data according to players' positions, it is evident that backcourt and wing players are at a higher risk of injuries. The majority of available studies have highlighted backcourt players to be more at risk for injury [5, 26, 27]. Wedderkopp et al. showed that young female back players had the highest overall incidence of injuries and the highest number of acute noncontact lower-limb injuries as compared with other player positions [9]. A retrospective study by Piry et al. of the 2008 Asian Handball Championships found 60.3% of injuries occurred to back players, whereas only 12.7% occurred to the wing players and 11.1% to the line players (pivot) [21]. A possible explanation for this trend could be that the majority of ball movements in the offense are done by the back players who therefore perform a substantial amount of planting and cutting movements as well as jump shots. In addition, they are involved in more aggressive contact than players at other positions, normally facing the biggest and strongest defenders in the opposing team.

A similar trend was observed by Moller et al. in their cohort of 517 elite-level players from Denmark, with injuries being more predominant in back court players, followed by wing players (in both genders and all age groups—senior, U-18, U16) [22].

Myklebust et al. have repeatedly shown that the relative risk of ACL injury is higher among back players [28–30].

In a year-long study of 186 players (male) in 16 senior German teams, Seil et al. [7] looked at injury distribution according to playing positions. Of the overall 91 injuries recorded, wing players sustained 36% of all injuries, backcourt players sustained 33% of all injuries, 19% occurred to line players, and goalkeepers sustained 12% of the injuries. An analysis of this data for match injury rates by position (injuries/1000 match hours) revealed 18.6 per 1000 player match hours for wing players, 17.1/1000 match hours for line players, 12.8/1000 match hours for goalkeepers, and 10.5/1000 match hours for backcourt players. Wing players also had the highest rate of serious and severe injuries in that study, followed by backcourt players, goalkeepers, and line players [7]. They also observed an increasing rate of upper extremity injuries (shoulder and upper arm) in wing and backcourt players as well as a high prevalence (89%) of shoulder overuse symptoms in these positions [7]. The higher injury rates among wing players in that study were attributed to greater variation in motion and stress patterns compared with other player positions. Frequent jumps and falls, a high number of contact situations with opposing players, and involvement in counterattacks (Fig. 12.3) seem to increase the injury rates for wing players.

A different pattern was observed in the 2015 men's world championships in Qatar where the highest total risk of injury was for line players, followed by wings, backs, and goalkeepers. For time-loss injuries, the risk was almost the same for line and wing players. These differences from previously reported incidence rates could be explained by the fact that unlike previous studies which did not take exposure into full consideration, the data from Qatar was analyzed through distribution of the total exposure time (player-hours) in accordance with the most common team player formation (three back players, two wing players, one line player, and one goalkeeper) [31]. This may be an important starting ground for future epidemiologic studies in handball to better and closely evaluate exposure as well as taking it into a more accurate calculation when it comes to data analysis.

Fig. 12.3 A player in a shot attempt during a counterattack

12.1.2.1 Injuries According to Playing Level

Injury rate seems to be higher among players in higher-level leagues although there aren't any available studies which directly compared this aspect. Strand et al. reported early on that female players in the top three divisions have a higher ACL injury incidence than players playing at lower levels [32]. Myklebust et al. have repeatedly shown that the relative risk of ACL injury is higher among back players [28–30]. Data from Myklebust et al. suggested the proportion of ACL injuries in back players seems to be higher in studies involving elite players [30].

12.1.3 Injury Mechanism: Contact Vs. Noncontact

Most injuries in elite handball occur during player-to-player contact. Noncontact injuries mostly are related to the lower extremities, and in general those injuries are more severe (i.e., ACL injuries). Jumping, landing, and cutting maneuvers are the predominant situations leading to noncontact injuries. Luig et al. reported 30.6% of all injuries occurred during landing [11]. Studies at the top competition level show that contact injuries represent between 80 and 92% [20, 33, 34]. According to Langevoort et al. [20], about 50% of the injuries during major international tournaments are caused by a foul that is sanctioned; however, a decrease in the "foul play" injuries has been recorded for both men and women in the European championships in 2008 and 2010. In the men's Euro in 2008, only 25.5% of injuries were associated with foul play [35], while 39.6% were reported for the women's 2008 games [36]. In the 2010 men's Euro, only 11.1% of injuries were associated with foul play [37], while only 3.5% were reported in the women's 2010 Euro [38]. These high numbers are not the case when analyzing ACL injuries, which is a noncontact mechanism in the majority of cases when the player is performing a plant and cut maneuver or landing after a jump shot [28–30]. In the 2015 men's world championships, 61.4% were reported as the result of contact between players, while 15.9% were reported as noncontact trauma (the rest were overuse injuries) [31].

Giroto et al. reported 41.4% (35.8% in women; 48.5% in men) noncontact injuries in their cohort of 339 Brazilian elite-level players, while 34.6% (40.9% in women; 26.5% in men) were contact injuries [23].

Recent insurance company injury data from Germany focusing on all professional male player teams of the German national first and second leagues (Bundesleagues) revealed contact injuries were responsible for 78.1% of injuries, while 21.9% were noncontact [12]. Out of the contact injuries, 52.3% were defined as “direct contact injuries” where direct player-to-player or object-to-player contact to the injured structure caused the injury, and 25.8% were defined as “indirect contact injuries” where the contact was not directed to the injured anatomic structure and does not directly cause the injury but leads to a situation that subsequently causes the injury, e.g., knee injury during landing after a push against the chest while airborne, etc.

Unpublished data by Andersen et al. based on video analysis from the 2015 world championships suggested that a great majority of the contact injuries were under-sanctioned by the referees. Although decision-making regarding sanctions due to fouls is easier based on video and repeated viewing, it is clear that more could be done in this aspect as well to protect the players.

Fact Box
Most injuries in elite handball occur during player-to-player contact.

12.1.4 Timing of Injury During Matches

Trying to analyze WHEN do injuries occur in handball, reports are not always consistent. Dirx et al. revealed a higher injury incidence during the second half of matches, which was attributed to increasing player’s fatigue and intensity of close matches [4]. Asembo and Wekesa reported that 57% of injuries occurred in the second half [33], while Langevoort et al. reported that 45% of the injuries occurred in the middle 10 min of each half and decreased toward the end of each half [20]. Seil et al. interestingly noted up to 10% of all match injuries occurred during the warm-up phase, which can be attributed to an inadequate and perhaps too intense warm-up [7]. Luig et al. looked at data from the first 2 professional German leagues between 2010-2016 and reported a similar injury distribution between halves, with the majority of injuries occurring in the last 10 min of each half (Fig. 12.4) [11]. It is important to note that these reports (and most other studies) do not take into account the minutes played by the injured player in that specific match, as well as the player’s exposure in the same week or even up until that phase of the season, and therefore should be looked at carefully.

Data from the 2015 men’s world championship showed more injuries occurred during the first half of the match compared with the second half (126.7 vs. 63.4 injuries/1000 player-hours, respectively) [31]. The difference between the first and second half was even higher for time-loss injuries (68.5 vs. 29.1 injuries/1000 h, respectively). The highest risk of injury was found in the second part of the first half (188.5 injuries/1000 h). Table 12.1 summarizes injuries by match time in elite-level international competition. It is evident from this data that there is a tendency toward more second half injuries in major competitions; however, it is not consistent and less significant when looking at the women’s data. One of the great difficulties in analyzing this data is that the majority is derived from major international competitions where exposure is not equal between teams as well as the fact that training exposure is not calculated (although may not be as important as during a full season). Full season data with more accurate exposure assessment would better help characterize and identify patterns in injury timing during matches and when players may be at risk.

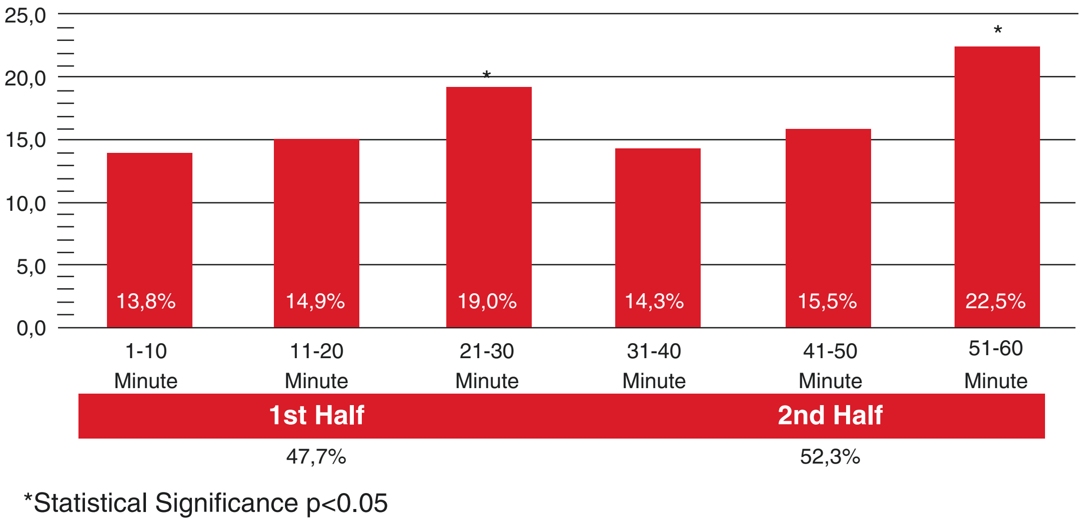

Fig. 12.4 Timing of injuries within games in the first and second German leagues in the 2010–2016 showing a very similar distribution between halves in these consecutive seasons, with a higher risk of injury in the last 10 min of every half [11]

Table 12.1 Timing of injuries within games in elite-level international competitions by gender

	Male					Female				
	2001 WC	2003 WC	2004 OG	2008 EC	2010 EC	2002 EC	2003 WC	2004 OG	2008 EC	2010 EC
First half										
1–10 min	11%	10%	13%		20% (1–15 min)	8%	7%	11%	17% (1–15 min)	12.9% (1–15 min)
11–20 min	13%	22%	15%		24.4% (16–30 min)	21%	21%	16%	38.3% (16–30 min)	21.2% (16–30 min)
21–30 min	13%	21%	13%			13%	20%	19%		
Total first half	37%	53%	41%	27.7%	44.4%	42%	48%	46%	55.3%	34.1%
Second half										
31–40 min	22%	16%	11%	38.3% (31–45 min)	20% (31–45 min)	13%	16%	13%	21.3% (31–45 min(	35.3% (31–45 min)
41–50 min	32%	22%	35%	34% (46–60 min)	26.7% (46–60 min)	29%	26%	22%	23.4% (46–60 min)	30.6% (46–60 min)
51–60 min	8%	6%	13%			15%	8%	17%		
OT	1%	3%	0			0	2%	2%		
Total second half + OT	63%	47%	59%	72.3%	46.7% (+8.9% in OT.)	57%	52%	54%	44.7%	65.9%

WC world championships, *EC* European championships, *OG* Olympic Games, *OT* over time
Data based on Langevoort [20] and Holdhaus [35–38]

12.1.5 In Which Phase Do Injuries Occur: Offense Vs. Defense

Evidence from major competitions as well as longitudinal studies shows the majority of injuries in handball occur during the offensive phase of the game (when a team is on offense), with reports ranging from 52 to 86% [2, 7, 26, 33, 34]. Several other authors showed the same trend with reports ranging from 77 to 92% of injuries occurring during the offensive phase of play [8–10, 39]. Two studies, however, showed a different trend, reporting a higher incidence of injuries during the defensive phase of the game. For example, Reckling et al. [6] stated that almost two-thirds of the injuries occurred during the defensive phase [21], as did Oehlert et al. who reported 84% of the injuries in their study occurred during the defensive phase [34]. Most players are injured in contact situations, and offensive players are more at risk than defensive players as the defensive player is the one who typically initiates the contact. Seil et al. found that approximately one-third of offensive injuries occurred during the fast break/counterattack phase [7].

A similar distribution of offensive injuries dominance was observed in the German insurance company registry of handball injuries in the top two divisions, with over 60% of injuries occurring during the offensive phase [12].

Fact Box
Most players are injured in the offensive part of the game.

12.2 Injury Type

12.2.1 Traumatic/Acute Injuries

The majority of injuries reported in handball, both in adults and adolescents, are acute injuries. In international championships, contusions are the most common injury type with an incidence between 44 and 60% followed by muscle strains and ligament sprains with 7–27% of all injuries [20, 33]. Data collected in the world championships in 2015 revealed the most common injury type was contusions (38.6%), followed by sprains (23.5%) and strains (12.9%). Muscle strains affected mainly the lower extremities (88.2%; mainly in the thigh and groin), while most contusions were located in the face (6.8%), thigh (6.8%), knee (6%), and lower back. Ankle sprains (15.9%) were the most frequent specific diagnosis [31]. Other studies have highlighted sprains as the most common injury type (46–68% of all injuries) [3, 7]. These results reflect different injury definitions in these studies. Muscle strains present an overall incidence of 6–26% [7, 9, 20, 27, 40]. Contusions range from 2 to 36% of all injuries [5, 9]. Fractures and dislocations are usually less common, but two studies noted exceptions to this observation. Fagerli et al. [5] reported the fracture incidence to be 19–22%; however, they studied emergency department records, which could explain the high numbers of fractures. Asembo and Wekesa [33] reported a fracture incidence of 31% among elite-level male players; however, these numbers are not consistent with the data of Langevoort et al. [20] among a larger number of elite-level players, where the fracture incidence was only 1%–2%. Moller et al. reported an overall incidence of 63% acute/traumatic injuries in a large cohort of elite-level senior and youth players in Denmark over a season [22]. The most common injuries were sprains/distortion (46%) followed by muscle strains (17%) and contusions (9%). Giroto et al. recorded 237 traumatic injuries of the total 312 injuries (76%) in Brazilian elite players over a full season [23]. Muscle strain/rupture/tear, sprain (joint and/or ligament), and contusion were the three leading injury types. Fractures comprised 4% of injuries in this study.

12.2.2 Overuse Injuries

Over the years there have been insufficient data regarding overuse injuries in handball; however, medical personnel who attend to handball players acknowledge their incidence is quite high. In their unpublished data, Gundersen and Myklebust observed that 41% of all injuries that required treatment were overuse injuries with the most common location being the shoulder (22%). They did not distinguish overuse injuries according to gender. In another study, the incidence of overuse injury to the shoulder of German players was reported to be 40% [41]. Similar high prevalence of shoulder overuse injuries were also reported by Nielsen and Yde where 8 out of 12 shoulder and elbow injuries were deemed to be overuse injuries; the total incidence of overuse injuries in their study was 27% of all injuries [3]. In the study by Leidinger et al., the most common locations of overuse injury were the knee (26.9%) and ankle (20.3%), but handball-specific overuse injuries like "throwing shoulder" and "throwing elbow" accounted for 17.1% and 11.9% of the overuse injuries [2]. Tyrdal and Bahr stated that 41% of 729 (male and female) goalkeepers reported current elbow injuries [42]. The condition was termed "handball goalie's elbow" and appeared to result from repeated elbow hyperextension trauma. These reports are consistent with the findings of Seil et al. [7] at the nonprofessional level, where one out of three goalkeepers suffered from elbow overuse symptoms; 66% of the players suffered from 183 overuse symptoms overall (n = 123). The shoulder was the most common region (19%), followed by low back complaints (17%) and knee (16%). In a study by Lian et al. [43] looking at "jumper's knee" among elite athletes from different sports, the total prevalence among male handball players was 30% and 10% among females [43]. Olsen et al. reported that lower-leg pain (periostitis) was the most common overuse problem [40].

Moller et al. reported 37% overuse injuries in their cohort of 517 elite-level senior and youth players from Denmark [22]. Prevalence distribution between senior, U-18, and U-16 players was 31%, 36%, and 45%, respectively. These numbers are slightly higher than previously reported by Wedderkopp et al. [9] and Seil [10] in youth players (7–21%). Shin splints (22%) were the most common overuse injuries, accounting for 35 of the 39 reported lower-leg injuries, followed by tendinopathy (22%) and bursitis (7%). The knee was the most commonly affected site after the lower leg, followed by the shoulder. Clarsen et al. studied the prevalence and impact of overuse injuries in Norwegian sports, including 55 handball players [44]. They reported the shoulder was the most common site of injury for overuse injuries (22%) followed by the knee (20%); however, the knee was the most common site for substantial overuse injuries (8%) compared to the shoulder (6%).

Bere et al. recorded 12.1% overuse injuries during the 2015 men's world championship; however, this is probably an underestimation as it is likely that many players played despite overuse injuries and pain and did not wish to miss the opportunity of playing at the front stage of international handball [31]. Giroto et al. reported a prevalence of 24% overuse injuries in elite Brazilian male and female player over a full season (25% and 23.3%, respectively) [23]. Of those, the majority of overuse injuries were recorded in the shoulder (44%) followed by the knee (26.7%).

Luig et al. reported 11.2% overuse injuries in their analysis of first and second Bundesleague players (Germany) over three seasons, with 6.2% of overuse injuries causing time-loss of >28 days [45].

12.3 Summary

The game of handball is ever growing in popularity with the increasing involvement of different media platforms (Internet, TV, social media) and endorsements accompanying this type of exposure. This growing popularity attracts more and more participants, as well as the variations of the game, such as beach handball and street handball. The natural evolution of the game of handball has resulted in more intense competition at the top levels. The combination of greater intensity and the frequent matches played in multiple competitions (and the resulting loss of recovery time between matches) places the players at high risk for injuries.

Data from existing epidemiologic studies in handball is not uniform in its methodology, a fact that may explain some of the inconsistencies in various observations. Yet several patterns have been recognized. The majority of injuries occur during matches when compared to training[3, 7], and more injuries occur during the offensive phase of the game compared to the defensive phase [8–10, 39]. Lower extremities account for most of the acute injuries, followed by injuries of the upper extremities and head injuries. Sprains and contusions are the predominant injury types. Knee injuries represent by far the largest share of severe injuries, and women are clearly more vulnerable to knee injuries, in particular to ACL tears. Backcourt players seem to sustain more injuries compared to other player positions, followed by wing players.

The majority of injuries in handball are contact induced, and since up to 50% of the injuries are "foul play" related, referees have an important role in protecting the players and enforcing fair play. An emphasis should clearly be directed to this aspect.

Sufficient data regarding overuse injuries is especially limited [46]. As these injuries sometimes draw less attention and are less dramatic than acute injuries, many players choose to keep playing with overuse injuries and pain despite the consequence of a reduced performance level. Overuse injuries often possess a real challenge and are difficult to manage within the tight schedule typical at the highest competitive levels. Better characterization and understanding of the extent of overuse injuries in handball are necessary and should be the focus of future studies [47, 48].

Another important aspect when trying to understand injuries and their effect on various populations is their long-term consequences. Such studies are sparse in handball players; however, few studies looking at the rates of osteoarthritis in former handball players suggest this should also be an important focus of future studies [47, 48].

It is clear that Injuries are part of a handball player's career span. A better understanding of injury types and mechanisms can aid with injury reduction and improved injury management. Improved knowledge on injury mechanisms is also required in order to plan and incorporate appropriate and effective prevention measures. Well-designed studies addressing the specific demands and needs of handball players will improve the understanding of these issues and help apply the derived conclusions in all aspects of the game, from national and international competition schedules, to protect players, educate coaches, and provide guidelines for referees to better balance permitted contact with players' safety.

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13

Head and Neck Injuries in Handball

Markus Wurm and Lior Laver

13.1 Introduction

Over the last decades, handball has become a much faster as well as physical and technically demanding team sport. This was not only the result of the numerous changes in the rules of the game (i.e., different surface texture, time-out periods, etc.) but also with the result of the growing physical requirements of players which have led to a comprehensive development in handball. These changes have contributed to an increased injury risk over the last years.

Head and neck injuries are among the most dreaded injuries with potentially long-term sequelae.

Handball is not only an overhead and pivoting sport but also a contact sport, where physical contact is of high frequency. The combination of less restrictive rules with regard to contact with the dynamic nature of the game and the frequent attempts of cutting maneuvers can lead to substantial head, face, and neck injuries.

Besides bodychecks and hits, which account for the most frequent type of injury and are mostly without permanent handicap, loss of eyesight or injuries to the cervical spine, with potential life-threatening conditions, have to be kept in mind as incisive trauma.

Along with the changes in the rulebook as well as the growing fast nature of the game, there have been great advances with regard to protective measures and injury prevention.

Mouth guards (i.e., teeth protectors and gumshields), well known from boxing and mixed martial arts sports, have also found their way into handball.

Not only "direct" injury prevention by use of protective gear but also "indirect" ways have evolved to date. Video analysis of games has become a standard in major competitions in handball not only for tactical reasons but also for detecting injuries and to future injury anticipation [1].

13.2 Mechanisms of Injury

The head as well as the face is one of the most prone parts for injuries in handball. Thrown handballs can reach speeds exceeding 100 km/h [2]. Also the pivoting moment of a thrower's arm/hand reaches high velocities, which potentially hit the opponents' head or neck region. Especially "standing throws" or "standing throws with "run-

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up," for instance, are a well-known injury pattern. During the "cocking" and "acceleration" phases of the throwing motion of the attacking player, the hand and ball are, depending on opponent players' height, typically at or above the defending player's head. At "ball release" and going into the "follow through" phase of the throwing motion, the throwing hand is in descend and could hit the defender/s head, face, or neck region [3]. Defensive players, however, try to target the ball and block it with their hands typically raised above the head. Assuming this position, the head and face are disposed to injury. Therefore, defenders try to prevent injuries from their face and head by rotating their face to one side tergiversate the ball. However, the throwing act itself is only one potential injury mechanism but showed up to 22% of injuries in findings from 2011 [4]. Trying to keep the opponent from throwing brings us to the most frequent injury type. Overall the "throw" itself accounts for up to 31% of injuries [5].

Disregarding the mechanism itself, the most common encountered cause for injuries to the head and neck region is foul play as Langevoort et al. and various other studies discovered [1, 6]. Overall the most common found injuries in team handball are due to contact between two players and account for up to 90% of injuries [7]. This goes along with numbers from 2015/2016, which showed contact-related head injuries in 87.8%. Overall foul play was responsible for 41.5% of all head injuries [5]. Noncontact injuries are common seen in ACL ruptures due to jumps and insecure landing, for instance (see Chaps. 19 and 20), and only represent 2.4% of head and neck injuries [5].

Performing counterattacks, players generate high speed levels while sprinting onto opponents' goal. Counterattacks do account for approximately 1/3 of offensive occurred injuries according to findings by Seil et al. in 1998 [2]. Collisions of offensive players and goalkeepers, for instance, can be a cause for severe injuries to the head and neck. While the offensive player starts his sprint toward the opponents' goal and turns his/her head to maintain eye contact with ball and receive the pass from his teammate similar to a long quarterback's pass in American football, the rival goalkeeper tries to intercept this pass in advance. In these situations, the attacking player is often not aware of or can't see the goalkeeper rushing toward him. Due to these circumstances, severe collisions have occurred in the past. This scenario should outline the importance of rulebook changes since it has been a subject of long debates and controversies. This furthermore illustrates how rules may affect various game situations and in this specific scenario help prevent severe injuries during handball training and competition.

13.3 Injuries

Information on prevalence counts and injuries in handball are mainly based on findings from publications of the 1980s and 1990s of the twentieth century [2, 8–13]. This information is accompanied by database gatherings like Germanys' "VBG Report." This report has been released in its second edition and is focused on the two highest handball leagues in Germany (Handball Bundesliga, 2. Handball Bundesliga). The report is presented annually by the national accident insurance of Germany (VBG). The reported data is only representative for male athletes. To date the available data has been interpreted in many different aspects. Age and sex of injured athletes as well as position play and time of injury during game or training have been evaluated.

Only a few national and international work groups have been gathering information over playing season as well as at European and World championships as well as Olympic games within the last years [14–18]. According to results from Langevoort et al. in 2007, incidence numbers are slightly higher nowadays. Between 89 and 129 injuries/1000 match hours in male athletes as well as 84 to 145 injuries/1000 match hours in female athletes have been reported. Twenty-three percent of injuries located around the head and neck is the second most common injury site after the lower extremity injuries (42%). Furthermore, contusion of the head was found to be the most frequent diagnosis with 14% [6]. Seven percent of all occurred injuries during the 2015/2016 season in the German Handball Bundesliga and 2. Handball Bundesliga were related to the head [5]. In 2011 Piry et al. found the injury incidence amazingly higher in Asian population with 20.7 injuries/1000 game hours and 0.96 injuries/1000 training hours, respectively, whereas head and neck injuries were mostly a result of contact [4, 19]. The VBG report revealed 77.7 injuries/1000 hours of game play which accounts for 52.4% of injuries [5].

However, these findings are indispensable to help working on prevention strategies but have to be expanded in general and applicable ways, as has been shown by Olsen et al. or Langevoort et al. [6, 20]. Data from a video analysis of the 25th World Championships in Qatar has shown head and neck injuries to be the most often encountered injuries (31%) as well as opponent contact the most often reported mechanism (49%) [21]. Bere et al. reported on 12.9% of injuries to the head and face to be due to contact during this world championships. They furthermore stated no absence of 11 athletes after sustained facial injuries. Two athletes were absent for max. 2 days, and two athletes were absent for more than 3 days [14].

Obviously, wearing protective equipment can prevent injuries. Especially goalkeepers are at high risk and are frequently protected by special gear [2]. Eye injuries should be prevented, and the use of protection glasses is not rare in contact sports.

Another important fact should also be kept in mind. Position play is another factor, which has to be considered. Wingers, for instance, showed less injuries with regard to dental trauma than compared to goalkeepers [22]. Another finding from 1998 was the highest incidence of injury among wingers. Other studies suggest the highest injury rates in the left and right back position (41%) compared to 19% of center backs and 12% in wingers [4, 19, 20]. Laver and Myklebust already presented what was proven by the VBG in 2015/2016 [19]. They showed highest injury counts for pivot (83.5%) and backcourt players (83.1%). Overall a pivot player had 2.8 and backcourt players 3 injuries throughout 2015/2016. Pivot players were the ones with the highest injury levels with regard to the head and neck region (9.6%). This can be traced to competition for space at the handball circle [5]. This goes in line with findings from Bere et al. who reported the highest injury rates in line players (pivot) [14].

13.3.1 Concussion

A concussion has earlier been considered a “mild traumatic brain injury” (mTBI) [23, 24]. The fact it is called “mild” often lead to the circumstance it is disregarded or neglected due to only insignificant appearing symptoms. This course can lead to subsequent brain damage and every team physician should know about the potential secondary damage. Todays’ understanding of concussions is even more differentiated. The fact there is a well-defined nomenclature (“sports-related concussion (SRC)), which has been introduced many years ago, should further highlight its importance. Since the 1970s of the twentieth century, physicians were eager working on this special sports-related entity [24]. McCrory et al. recently presented the “consensus statement on concussion in sports.” “The SRC is caused by a direct blow to the head, face or neck or elsewhere on the body with an impulsive force transmitted to the head (…) it typically results in the rapid onset of short-lived impairment of neurological function that resolves spontaneously. The clinical signs and symptoms cannot be explained by drug, alcohol, or medication use, other injuries or other comorbidities” [24, 25].

Team physicians should be well aware of diverse symptoms like posttraumatic seizures, chronic-traumatic encephalopathy, or post-concussive syndromes. In case of a sustained concussion during a game or even training, the affected player should not be considered for further service until auxiliary medical clarification [23]. The sideline evaluation is a crucial factor due to rapidly changing clinical signs and symptoms. To date, there is no distinct diagnostic test, which makes the SRCs to be among the most complex injuries with respect to diagnosing. It

Table 13.1 Symptoms of sports-related concussions by the "CISG"

Somatic (e.g., headache), cognitive (e.g., feeling like in a fog), and/or emotional symptoms
Physical signs (amnesia, loss of consciousness, neurological deficit)
Balance impairment (e.g., gait unsteadiness)
Behavioral changes (e.g., irritability)
Cognitive impairment (e.g., slowed reaction times)
Sleep/wake disturbance (e.g., somnolence, drowsiness, etc.)

can present itself with almost no symptoms up to a complete loss of consciousness. Therefore, it is necessary to be aware of brief neuropsychological tests, which incorporates, e.g., the Maddocks' questions, the Standardized Assessment of Concussion (SAC), and the Sport Concussion Assessment Tool (SCAT5) [24, 26–28]. A fast screening for a suspected SRC is even more important than primary diagnosing it.

A great variety of symptoms can occur after sustained SRC. The most common are presented in the table below (Table 13.1).

After sustained SRC, it is important to reevaluate the athlete due to persistence or even aggravation of symptoms. In case of persistent symptoms, referral of the affected athlete should be considered to a specialist who should screen for potential structural damage. Further comprehensive history, focused physical examination, and special testing are recommended by the CISG [24]. To date there is no clear recommendation for adequate period of rest, yet athletes are obligated to refrain from their cognitive or physical thresholds. The rehabilitation phase has to be adapted to the individual symptoms of the affected athlete. This goes along with the recommendations for return-to-sport. A gradual approach to get back to sports has proven itself effective.

Concussions are only infrequently mentioned in to date presented studies. Seil reports on 4 head and neck injuries, which were found in a prospective study over a period of 1 year including 16 German handball teams. One of them being a nose fracture due to ball contact by a goalkeeper and one concussion which needed hospitalization were reported [2]. The degree of impairment after occurred concussion might also be one reason for scarce reference since athletes want to keep on playing and symptoms might not be pronounced enough for a break. Makdissi et al. conducted a systematic review on this vital subject in 2017. They state, "a detailed multimodal clinical assessment is required to identify specific primary and secondary processes, and treatment should target specific pathologies identified" [29].

The presented consensus statement by McCrory et al. clearly defined symptoms, the need for reevaluation, rest, and rehabilitation as well as a graduated return-to-school/return-to-sport strategy which constitutes as to date standard, yet the authors clearly state their consensus only as a guide and of general nature [24]. Nevertheless, the consensus statement helps health-care providers for fast assessment of the injured athlete and provides an eligible framework for diagnosing and treating SCR.

13.3.2 Orofacial Trauma

In 2007, Lieger and von Arx conducted a study with the objective to measure occurrence of orofacial trauma in different sports, including soccer, handball, ice hockey, and basketball. With regard to handball, they recorded 40% soft tissue lesions, 32% teeth fractures, and 1 loss of a tooth [19, 30]. Their findings are similar to the ones reported by Badel et al. in 2007 with more than 78% soft tissue trauma, 13.6% dental trauma and loss of teeth, as well as 8.6% temporomandibular joint injuries [31].

Dental trauma has been reported to be 12.9% at the 2015 handball World Championships in Qatar. Fifteen percent of injuries were estimated to the head and neck overall. Also the mechanism has shown to be contact-related in over 82% [14].

Recent data from Bergman et al. on the prevalence for head and neck trauma in professional handball players from Croatia reveals relatively high rates. They recorded 7% head injuries, 16% eye and periorbital injuries, 18% nose injuries, 19% lacerations, as well as 1 fractured jaw/facial bone. Dental injuries were reported with 14% [19, 22].

The first and second “Handball Bundesliga” reported on 9.1% of dental trauma as well as 14% fractures related to the head region during the season 2015/2016 [5].

Gialain et al. reported on a case of a relatively common mechanism of orofacial trauma which is representative for handball. The injured player suffered a “punch-like” blow to the face during game play. Clinical examination by a dentist revealed an upper lip laceration, upper left lateral incisor subluxation, and anterior nasal spine fracture. They concluded that substantial teeth damage could have probably been prevented by use of a mouth guard [32].

Lacerations are a common entity and companion in indoor athletic sports overall and occur due to contact and noncontact situations [8]. The VBG reports on 23.1% of skin lesions of the head [5]. A fall during sprinting and subsequent grinding can lead to a laceration of the skin [33].

13.3.3 Injury Prevention

Injury prevention strategies vastly developed in the last three decades. Much has happened in the fields of sports injury prevention and awareness since Fagerlin et al. reported in 1990 on partly inadequate medical care and the need for preventive strategies, and we are very well aware of the potential benefits of implementing such strategies to date [19, 34]. They identified the need for better basic and technical training as well as adequate first aid and amendments to the rulebook in handball. Little is known about specific injured anatomic structures since they are not universally registered in a database, as we know it from championships or Olympic games. Another paucity of information regards ocular/eye injuries.

Protective equipment such as pads or braces for the elbow, hip, knee, or ankle joint are commonly used in handball and are aimed to protect commonly injured anatomic regions. In contrast to other anatomic regions, the head and neck regions are insufficiently protected in handball players. Apparently, a helmet, as we know it from, e.g., football players, would likely be considered reducing extent of injury albeit we know that concussions are not being prevented by helmets [23]. Players who sustained injuries to their eyes can be often seen with special goggles to prevent further or subsequent damage. One spectacular example is Karol Bielecki (Polish left back) whose eyelid and eyeball were injured in 2010 during a friendly game. Despite loss of his eyesight, he gave his debut after 3 months convalescence and scored 11 times in his first Bundesliga game.

Results of Lieger and von Arx’ findings suggest the wear of mouth guards as one favorable preventive strategy for teeth fractures/loss. They reported on 31% of orofacial injuries without wearing a mouth guard compared to 7% wearing a teeth-protecting gumshield [30].

Bergmann et al. also indicate the plausibly better results wearing mouth guards in handball. During a period of 12 months, nine fractured teeth (no mouth guard) were recorded in contrast to no fractured teeth wearing a mouth guard [22]. Particularly in cases of dental trauma, storage media for lost or fractured teeth are essential and need to be available on-site. This is especially important to preserve the option of reimplantation due to functional, psychological, and health-care-related factors [35, 36]. Ozbay et al. reported findings with regard to traumatic dental injury in handball players in 2013. They reported on a lack of knowledge not only in adult handball players but also trainers, adolescent players, their parents, and staff. Of 212 included participants on this questionnaire-based study, 41 (19.3%) reported on a previous sustained traumatic dental injury. Most of these trauma occurred during match and due to a direct mechanism [37]. This further indicates why a team physician and dentists should always be present or quickly available during match and training [31]. The “IHF clothing and equipment guidelines” are annually renewed and have to be followed by players and staff. This guideline also provides information for permitted protecting gear [38].

Today we are well aware of different other sports and well-established prevention programs (soccer, volleyball, basketball, etc.). Increased training hours can lead to a reduction of injuries. Not only proprioceptive and sensomotoric training in athletes have shown to reduce the likelihood of adverse events but also aimed strengthening exercise and adequate rest especially in youth athletes is essential [39–44]. All sort of strategies obviously affect musculoskeletal system, whereas the head and neck are most likely to be underrepresented. With regard to these regions, special attention should be drawn on rest and aimed training on mental fitness to avoid fatigue due to the fact that most injuries were found to occur during the second half of a game. Especially between the 51st and 60th minute, 22.5% of injuries were recorded by the VBG [5, 33]. Many elaborate approaches in terms of injury prevention have been introduced not only for handball. Sometimes, athletes exactly know the risk of injury but do not wish further prevention since they find the use of protective wear restrictive and limiting for game play [30].

Fact Box
Mouth guards have been proven effective in preventing teeth trauma [22, 31, 32].

13.3.4 Return-to-Sports

Every head and neck injury needs to be treated in particular and by a specialist. There is no default "return-to-sports period" for any injury. As can be seen in the Karol Bielecki's tragic case, a fast return (3 months posttrauma) to sport is possible, but several contrary examples exist which may have not had the same public impact. Athletes have to be educated in sustained injury, and the posttraumatic course has to be discussed with staff to set realistic goals.

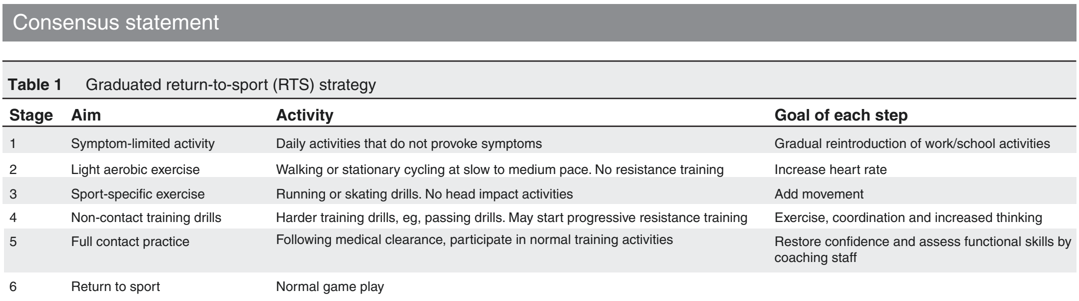
Soft tissue trauma, like lacerations, is in need of regular follow-ups with regard to adequate wound healing and to prevent potential infection.

Contusions are a well-known entity and common injury associated with handball due to the fast character of the game. They are often to be followed by radiographs to rule out fractures. In case of a contusion, the return-to-sports can be fast. Yet "whiplash"-like injuries can lead to contracture of surrounding neck muscles and should to be treated with rest [45]. Furthermore, osteopathic treatment has shown efficacy and beneficial results for whiplash injuries in a relatively small cohort [46]. On the other hand, a representative review on 5204 participants with "whiplash-associated disorders" (WAD) came to conclude "optimal management of "WADs" focuses on reassurance and education instead of intensive care" [47]. These contradictory strategies also reveal the need for consensus with regard to this type of injury.

Fractures, especially ones involving the face or jaw, could potentially require surgical treatment. For return to play, the fracture needs to be consolidated, and regular follow-ups should be maintained with a specialist for final clearance before safe return to handball activities.

In case of mild traumatic brain injury and full recovery of symptoms, the athlete may return-to-sports after 1 week if no further symptoms remain. A systematic review on prognosis and return to play from 2014 states "delayed recovery appears more likely in high school athletes, in those with a history of previous concussion, and in those with a higher number and duration of post-concussion symptoms" [48]. Another more recent systematic review on literature reports "underuse" of rest by healthcare providers. They further indicate a more patient and individualized treatment. However, probably the most important statement is the "significant need to translate knowledge of best practices in concussion management to primary care providers" [49]. The "Team Physician Consensus Statement" further clearly specifies "no same day return to play for the concussed athlete" [23]. This differentiated approach goes along with the most recent consensus statement presented by McCrory et al. in 2017. They showed a graduated return-to-school as well as return-to-sports as depicted in Figs. 13.1 and 13.2.

Furthermore, they published an infographic, which shows a caricatured way of ideal handling concussions in athletes [25]. This approach can not only be applied to school but

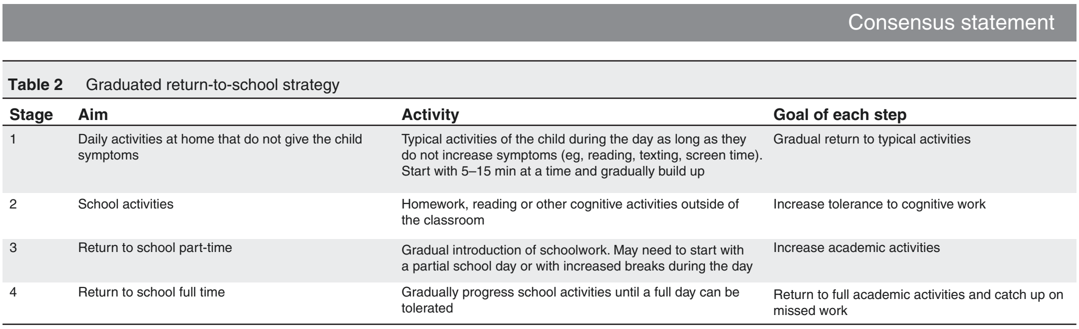


Consensus statement

Table 1 Graduated return-to-sport (RTS) strategy

Stage	Aim	Activity	Goal of each step
1	Symptom-limited activity	Daily activities that do not provoke symptoms	Gradual reintroduction of work/school activities
2	Light aerobic exercise	Walking or stationary cycling at slow to medium pace. No resistance training	Increase heart rate
3	Sport-specific exercise	Running or skating drills. No head impact activities	Add movement
4	Non-contact training drills	Harder training drills, eg, passing drills. May start progressive resistance training	Exercise, coordination and increased thinking
5	Full contact practice	Following medical clearance, participate in normal training activities	Restore confidence and assess functional skills by coaching staff
6	Return to sport	Normal game play	

Fig. 13.1 Graduated return-to-sport strategy by the "Concussion in Sport Group" (CISG) 2017



Consensus statement

Table 2 Graduated return-to-school strategy

Stage	Aim	Activity	Goal of each step
1	Daily activities at home that do not give the child symptoms	Typical activities of the child during the day as long as they do not increase symptoms (eg, reading, texting, screen time). Start with 5–15 min at a time and gradually build up	Gradual return to typical activities
2	School activities	Homework, reading or other cognitive activities outside of the classroom	Increase tolerance to cognitive work
3	Return to school part-time	Gradual introduction of schoolwork. May need to start with a partial school day or with increased breaks during the day	Increase academic activities
4	Return to school full time	Gradually progress school activities until a full day can be tolerated	Return to full academic activities and catch up on missed work

Fig. 13.2 Graduated return-to-school strategy by the CISG 2017

also "to work" or "daily living." This staged procedure illustrates the gradual return to typical activities of daily living followed by a stepwise increase on cognitive work and academic activities as well as light aerobic exercise from walking and stationary cycling to full sportive activity. The complete return-to-sports is depending on the sustained impact and the degree of suffered concussion. In case of remaining symptoms, the athletes should not get permission for return until complete remission of symptoms.

13.3.5 Summary and Future Perspectives

Prevention is only one yet important factor to obviate injuries in handball. New prevention strategies (i.e., protective clothing, training techniques, etc.) need constant adaption to changes in handball.

Various prevention strategies aim for the same goal: preventing potential harm as well as subsequent damage in case of occurred injuries to athletes [31]. Yeung et al. presented a new Risk Assessment Tool (SOCRAT, Sports Organization Concussion Risk Assessment Tool) in 2017. They state "it can be used to analyze how different risk factors contribute to the overall risk of concussion" [50].

Therefore continuous national and international education programs and meetings need to be advanced for coaches, players, and staff. Protective wear has a much higher impact with regard to the head and neck than, for instance, compared to other regions of the body.

Diagnosis and treatment of head and neck injuries should be performed by a specialist (dentist, neurosurgeon, etc.) to provide optimal care and reduce absence time for the athlete.

In case of sustained concussions, the athlete should be taken out of sport until full recovery of symptoms. Stepwise return-to-sports is well portrayed by the consensus statement of the CISG [24].

Fact Box
Concussions are an insidious impairment, and symptoms can often be scarce. Awareness should be drawn on fast diagnosis. In case of related symptoms (dizziness, headache, amnesia, nausea, vomiting, etc.), athletes should be taken out of the game until full recovery of symptoms [23, 49, 51].

13.4 Take-Home Message

Head and neck injuries in handball are frequent and need to be taken serious due to their potential consequential damage. Quick and adequate first aid needs to be provided by an on-site physician. Protective equipment like mouth guards have proven their efficacy in preventing injuries. Awareness for the use needs to be established not only in athletes but also the surrounding staff.

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14 Shoulder Injuries in Handball

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14.1 Introduction

Shoulder injuries are frequent in handball activities; they can affect the performance and can even compromise the career of some players. The shoulder injuries are the results of continuous forces that are concentrated on the shoulder during the movement of throwing. While a single traumatic event can cause injuries of the shoulder, in most cases, the overuse due to repetitive movement causes progressive damages of the anatomical structures.

In order to throw the ball with maximum velocity, the shoulder must reach extreme positions of rotation, but at the same time, the humeral head must remain within the glenoid socket, that is known as the "thrower's paradox". The shoulder must have a compromise between stability and sufficient mobility. During each throwing movement, the soft tissues covering the shoulder are exposed to high loads which may ultimately reach the tissue's failure threshold, hence making it susceptible to an injury. The repetition related to the demands on exerting high-velocity throws can modify the stability-mobility status that is the main factor leading to an injury [1].

There is still controversy regarding the biomechanics and the underlying pathology of shoulder injuries in handball players. Repetitive throwing movements can cause multiple changes involving bony and soft tissue resulting in increased external rotation and limited internal rotation. These adaptive changes can lead with time to pathological kinematics as well as glenohumeral internal rotation deficit (GIRD) and scapular dyskinesis. These changes will make the shoulder susceptible to tissue failure, potentially resulting in partial rotator cuff tears, specific labral tears (posterior and SLAP) and acromioclavicular joint arthropathy.

Recent studies in biomechanics have helped in broadening our understanding of the pathogenesis of shoulder injuries in athletes [2–4].

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Moreover, quantitative analysis about biomechanics and kinematics, both normal and pathologic, has improved monitoring and management of the athletes more effectively in terms of prevention, treatment and rehabilitation modalities. The most commonly studied model in the literature with regard to the overhead athlete is the baseball pitcher model. Many biomechanical factors are common to all overhead throwing shoulders, but the handball shoulder has some further specific biomechanical aspects distinguishing it from other throwing sports.

Conservative treatment is the mainstay of management for most pathologies in the handball player's shoulder; however, surgery may be indicated in specific cases. Prevention of shoulder injuries in handball players has been shown effective and should be the focus of future efforts to reduce their prevalence.

This chapter describes the extent of the shoulder injuries spectrum in handball, common pathologies and their management and lay the background for subsequent chapters discussing assessment and rehabilitation concepts for the handball player's shoulder.

14.2 Epidemiology

In comparison to other popular throwing sports, such as baseball, handball shoulder studies are sparse in the literature. Despite this fact, since the 1990s, several epidemiologic studies have been performed in handball; however, it is difficult to compare between the data as the definition of injury and the methodology it was collected with can differ from one study to the other [5–9]. It is important to remember that non-time-loss injuries are also prevalent in the handball population. An overuse injury with chronic symptoms can affect a player's performance without real-time loss as per definition.

Looking at results from the different epidemiological studies over the past two decades, if we consider all types of injuries, the overall injury risk in handball is 2.5–8.3 per 1000 playing hours. In general, body contact, landing and running are the main mechanisms and situations in which handball injuries occur. There is also some specificity depending on the player's position [5, 10, 11]. The shoulder represents between 4% and 27% of all handball injuries [5–9]. This disparity is probably due to the fact that some publications considered only acute injuries, while others have regarded overuse injuries as well. Gohlke, in 1993, has shown that 40% of 25 examined players had been handicapped during training and matches during the past 6 months due to shoulder pain [12]. In the Norwegian elite division (178 players), 52% of male players experienced shoulder problems at some point during the season; 67% of those players who had pain suffered from reduced training performance, and 34% could not play matches due to pain [13]. An overall 58% of female Norwegian elite players reported a history of shoulder injury [11]. Lubiatowski et al. found multiple pathologies in their cohort of handball players: 13% were affected by significant GIRD (>20°), 14% had partial rotator cuff tears and 15% developed internal impingement [14]. These findings support an earlier report from Seil et al. who had already singled out the shoulder as the most common site for overuse symptoms in a longitudinal study [9].

Shoulder injuries are frequent in the handball population, with a predominance of overuse injuries. The handball shoulder represents a typical model for overuse injuries due to the repetitive nature of the throw. The combination of a throwing sport with frequent direct contact makes the sport of handball unique as well as the demands required from players and when it comes to injury-related decision-making.

14.3 Biomechanics

The majority of shoulder injuries in handball are caused by repetitive overhead activities leading to overuse injuries rather than by single traumatic mechanism. Handball is a fast-moving indoor contact sport. During a complete season, it was previously estimated that a professional team handball athlete performs up to 48,000 throwing actions per year with a maximum speed up to 130 km/h [15]. This estimation was made two decades ago, and the game has transformed substantially since then into a much faster pace; hence, it would be safe to assume that the current annual number of throws has increased. In addition to this high number of throwing actions, handball players throw with a wide variety of overarm and underarm techniques, and their shoulders are frequently exposed to contact and blocking while in an elevated position. Therefore, overhand throwing is a complex motion and has often been divided into phases and events in many biomechanical studies. The usual model in throwing shoulder in the literature is the baseball pitcher [16] which is probably the sport in which the greatest shoulder angular velocities are generated. Multiple studies have described and analysed the different phases of the throwing motion [4, 16–18].

The different phases of throwing, originally described in baseball, are chronologically the wind-up, the stride, the arm-cocking phase, the acceleration phase, the deceleration phase and the follow-through (Fig. 14.1). The first three phases take approximately 1.5 s in total. Although the duration of the acceleration phase is only 0.05 s, the greatest angular velocities and the largest change in rotation occur during this phase. Consequently, most injuries manifest during this phase [19]; however, they can occur at any phase. Therefore, it is important to determine at which phase the pain and the symptoms occur. It is also important to understand and be familiarised with the various throwing techniques in handball, as many of these techniques do not follow the classic baseball model of throwing with the clearly defined phases and not all of these phases exist distinctly in all techniques.

The velocity and the accuracy of motion is achieved by transferring the energy through the "kinetic chain" of the athlete [2]. At the initiation of the throwing motion, energy is generated in the legs and trunk, and then transferred from the lower body and the trunk to the shoulder, elbow and hand and ultimately carried onto the ball. The velocity of the ball is determined by the efficiency of this sequence/chain. The position of the lower legs, body rotation, the timing and the position of the scapula are all key elements in the kinetic chain. Any weakness or imbalance that alters the components of the kinetic chain, especially the lower legs and the trunk, can lead to a dysfunctional shoulder and ultimately a potential risk for upper extremity injuries [4].

The scapula plays an important role in appropriate shoulder mobility being the link between the thorax and the upper extremity, with the serratus anterior, trapezius, rhomboids, and levator scapulae providing scapulothoracic fixation. The acromio-clavicular and coraco-clavicular ligaments are the only other subordinate attachments of the upper limb to the thorax, hence enabling the shoulder to have the most considerable range of motion of any joint in the body. Therefore, the role of the scapula is to provide a stable structure for the humeral head during rotation and elevation, while exerting forces from the lower limbs and trunk to the upper extremity and ultimately to the ball [3, 20].

In handball, the throwing movement is usually quick, and the involved player doesn't have the same preparation time as a baseball pitcher (Fig. 14.2). The position of the trunk can be different depending on the action performed. The arm cocking and the arm acceleration are usually overhead actions however can be often be gener-

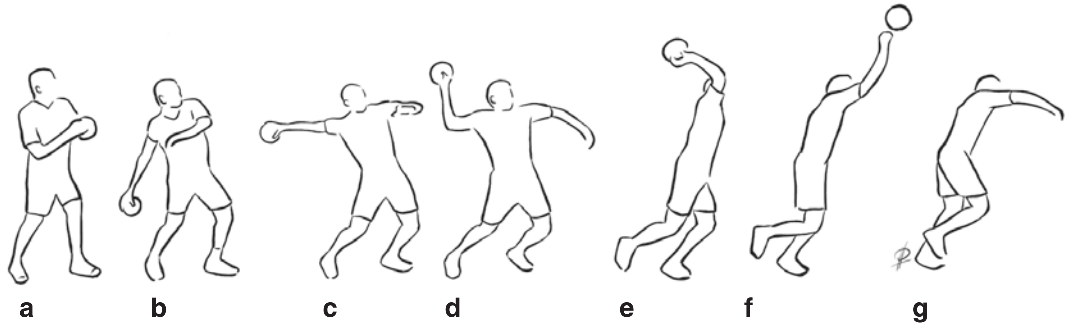


Fig. 14.1 The different phases of throwing in handball: (**a**) Run up, (**b**) wind up, (**c**) Early cocking, (**d**) Late cocking, (**e**) Acceleration, (**f**) Deceleration and (**g**) Follow through

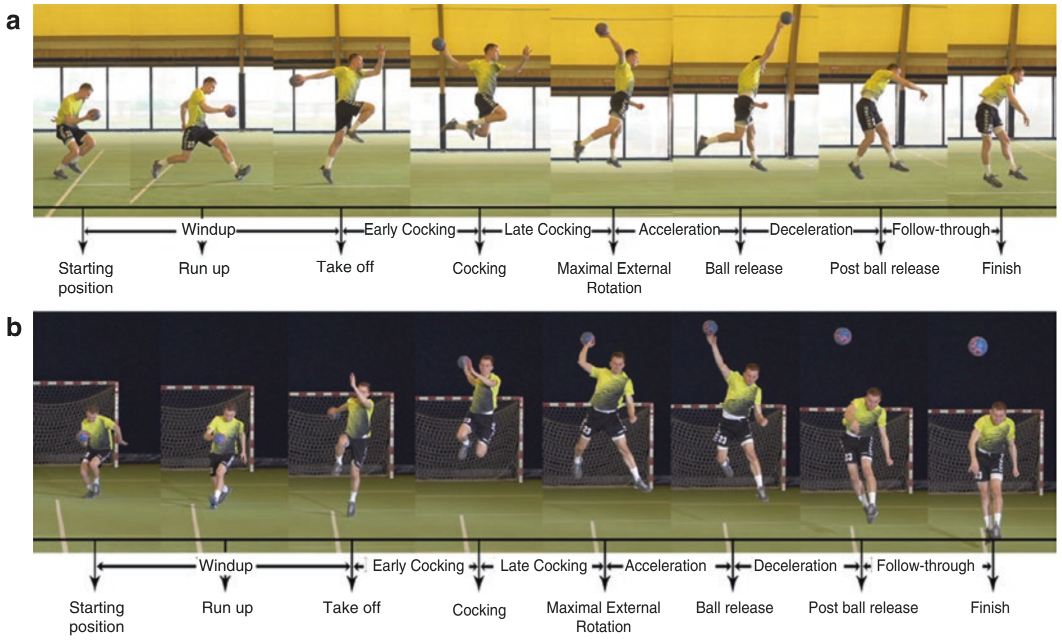


Fig. 14.2 Phases of a jump throw in handball: (**a**) in the saggital plane and (**b**) in the frontal plane. Courtesy of Piotr Kaczmarek and Przemyslaw Lubiatowski

ated at the level of the shoulder, waist or lower. After ball release, there is a deceleration which is shorter in time than for a baseball player, and the amplitude of the follow-through is usually small. Players often try to shorten the deceleration phase to avoid contact with another player during the follow-through phase (which is often absent), or it may be externally shortened by contact (a blocking attempt) from another player even during the acceleration phase or very early in the deceleration phase. Therefore, the effort to control deceleration is excessive. The blocking element, introduced externally by an opponent player, may potentially lead to different anatomic lesions. In summary, in the majority of the cases, the throwing movement in handball is fast and short, extremely variable and less predictable compared to other overhead throwing sports.

The dynamic analysis of the shoulder during throwing has improved our knowledge of normal and abnormal shoulder function, as well as which muscle groups are active during each phase of the throwing motion, which has helped to develop injury prevention and rehabilitation programs [21].

Fact Box

The majority of shoulder injuries in handball are caused by repetitive overhead activities leading to overuse injuries rather than by single traumatic mechanism.

14.4 Anatomical Adaptations

The repetitive throwing motion as well as the high forces subjected to the shoulder may cause adaptative changes in the dominant extremity [18, 22].

These modifications can affect both the soft tissues and bony structures in and around the shoulder. The arc of motion (defined as the angle from maximum internal to maximum external rotation of the abducted arm) of the dominant arm of asymptomatic high-level handball players, as other overhead throwing athletes, is typically shifted posteriorly, with increased external rotation and decreased internal rotation of the abducted shoulder [23, 24]. Laxity and range of motion of the throwing arm are also likely to change. The total arc of motion (both internal and external rotation) has been reported to be larger in handball players comparing to non-throwing population, but to an extent probably less than for baseball players [14], with typical shift to increased external and decreased internal rotation in throwing shoulder. One theory is that the increase in external rotation is caused by an adaptive increase in humeral retroversion [25] and that any substantial internal rotation deficit (of >20°) is therefore related to soft-tissue adaptation and pathology. In addition to the acquired retroversion of the humerus, there may be increases in bone mineral density in the throwing arms of overhead athletes [19].

Another important restricting structure to external rotation is the anteroinferior glenohumeral ligament. Repetitive ligament stresses may lead to micro-tears in the collagen fascicles and capsular laxity, which would also allow increased external rotation [26, 27].

Adaptive muscular modifications in dominant shoulders of throwing athletes may also occur. It is not uncommon for these athletes to have hypertrophy of the shoulder girdle and arm muscles. However, there are also reports of loss of external rotation strength of the dominant shoulders of throwers, with simultaneous increases in internal rotator muscles and adductor muscles strength [28]. This resulting imbalance between ER strength and IR strength has been linked with shoulder pathology [29].

Fact Box
The result of recurrent movement of throwing and high forces causes adaptative changes in the dominant extremity.

14.5 History and Symptoms

Obtaining a thorough history is a crucial part of any diagnostic process, and being familiarised with the common complaints in the sport is therefore important. Shoulder pain is a common complaint in handball players; however, it doesn't necessarily cause absence from play/training as previously shown [11]. Other complaints may include unexplained loss of throwing velocity and throwing control. It is important to understand and try to isolate at which phase of the throwing movement/sequence the symptoms occur. Although most serious shoulder complaints/pathologies in handball are related to overuse and have a chronic nature, acute injuries are not rare and may even occur on top of an already symptomatic shoulder, leading to symptom aggravation. Exploring recent alterations in throwing biomechanics and technique as well as increases in training loads in previous weeks is also important as abnormalities may occur as a consequence of such changes [30].

As previously mentioned, pain is a frequent symptom in dominant shoulders of handball players. Myklebust et al. showed in a study of 179 female elite handball players that 57% were affected by previous or current shoulder pain [11]. Thirty-six percent of the players reported having shoulder pain on the day of the evaluation, while 22% of the players reported experiencing previous shoulder pain. Two-thirds of the players with pain reported a gradual onset [11]. Clarsen et al. [13] reported findings in 206 male players in the Norwegian elite handball league tested prior to the 2011–2012 season. The average prevalence of shoulder problems throughout the season was 28%. The prevalence of substantial shoulder problems, defined as those leading to moderate or severe reductions in handball participation or performance, or to time-loss, was 12%. It is clear from the literature that shoulder pain is a common symptom in handball players, while only few reports of instability complaints exist, although this topic has not been thoroughly explored.

In case of a true severe trauma, such as a true dislocation of the dominant or the non-dominant shoulder, or an acromio-clavicular dislocation, it is important to obtain data on the status of the shoulder previous to the trauma.

14.6 Physical Examination

The physical examination should not focus only on the shoulder or upper extremity. Observation is an important and integral part of the physical examination and should evaluate posture, static and dynamic shoulder position (during standing and gait) and overall alignment. The trunk and the lower limbs must be globally assessed in order to identify any compensatory movements.

Once the comprehensive examination has been done and the kinetic chain assessed, a focused evaluation of the affected shoulder can follow. A standard musculoskeletal clinical examination should be carried out paying special attention to tenderness, range of motion, stability, strength and special tests [31].

Fact Box
Shoulder pain is a common complaint in handball players. While laxity findings may be more common in handball players, instability symptoms are less frequent, and their significance is controversial.

14.6.1 Inspection

The clinical examination should be conducted with both shoulders adequately exposed to permit full inspection. Handball players often exhibit asymmetry of the shoulders because of overdevelopment of the muscles on the throwing/dominant side. Occasionally, specific muscle atrophy can be identified. The position of the scapula at rest should be cautiously inspected in order to detect any scapular tilt, rotation, elevation or depression. The same observation must be done dynamically through the range of motion (ROM) to identify any scapular winging, more often called scapular dyskinesis. The distance between the spine and the inferior angle of the scapula must be noted specifically to detect any subtle winging. Scapular winging is observed very frequently in throwing athletes, but it is not always pathological. Kibler described the scapular assistance test [32] to help identify pathological scapular winging. The test is performed with the patient seated and facing away from the examiner. The examiner places his hand on the inferior angle of the scapula, and the patient is instructed to elevate the shoulder in the frontal plane. During this motion, the examiner assists the scapula through protraction during forward elevation of the arm (Fig. 14.3). The test is considered positive for scapular dyskinesis if pain and symptoms are relieved by the assisted movement.

14.6.2 Palpation

All prominences must be palpated. Pain on the greater tuberosity can indicate impingement or rotator cuff disease. Pain on the posterior joint line is suggestive of internal impingement or posterior superior labrum pathology. The biceps tendon should be palpated in the bicipital groove in external rotation position. Tenderness at this level can be indicative of biceps tendinopathy or

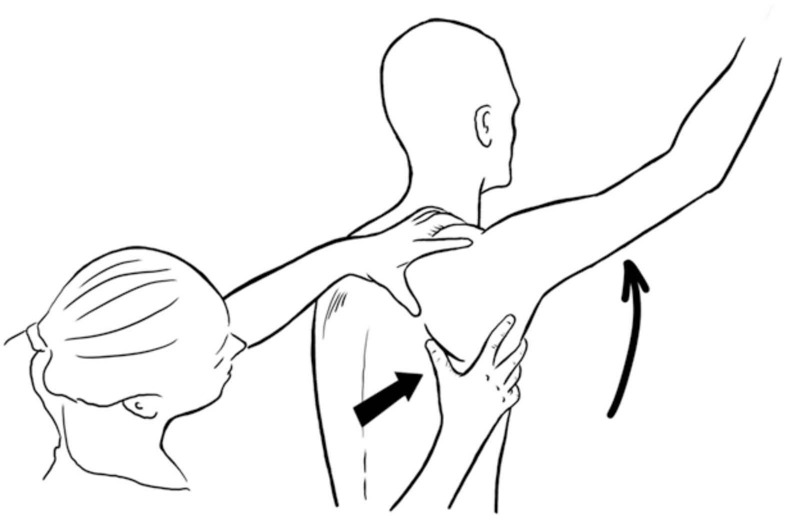


Fig. 14.3 The scapular assistance test

SLAP tear. Special attention must be paid to coracoid process tenderness which can be suggestive of pectoralis minor tendinopathy or tightness that is considered by some authors to be associated with scapular protraction and dyskinesis [33]. Pain lateral to coracoid maybe suggestive of subscapularis tear and bursal irritation and raise the diagnosis of subcoracoid impingement.

14.6.3 Range of Motion (ROM)

The ROM assessment should begin with a typical approach for all global directions, but then special attention should be paid to any abnormalities in ranges of rotation. It is probably best assessed with the player lying supine in order to stabilise the scapula on the table. Both shoulders should be tested and compared. The evaluation of the rotation starts with the arm placed in 90° of abduction and neutral position. Full external and internal rotation are then performed and measured. Handball players usually present increased external rotation and decreased internal rotation on the dominant throwing shoulder, but there is usually asymmetric "total arc of motion" in comparison to the non-throwing shoulder (Fig. 14.4).

Burkhart defined loss of more than 25° of internal rotation, compared with the non-throwing shoulder as GIRD (glenohumeral internal rotation deficit) [34]. GIRD can also be simply defined as loss of total arc of motion deficit on the throwing side as a result of decreased internal rotation. It has been shown that 20° loss of internal rotation is associated with increased risk of injury [29]. GIRD can be a consequence of posteroinferior capsular contracture. Some authors have described that posterior capsular tightness can be demonstrated also by stabilising the scapula on the examination table and moving the arm in crossarm adduction until the scapula starts to move [31]. However, a study conducted by Tokish on 23 baseball players showed that GIRD is a common finding in asymptomatic professional pitchers and related to humeral retrotorsion. He concluded that internal rotation deficit should not be used as the sole screening tool to diagnose the disabled throwing shoulder [35].

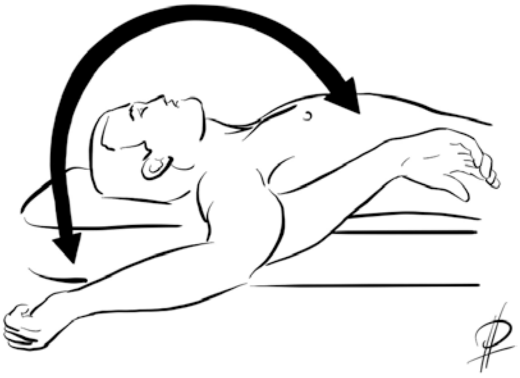


Fig. 14.4 The total arc of motion of the throwing shoulder is usually shifted posteriorly, with increased external rotation and decreased internal rotation (GIRD)

Nevertheless, the accurate evaluation for the total arc of motion is crucial in handball players. A study by Almeida et al. evaluated glenohumeral range of motion in handball players with and without throwing-related shoulder pain [36]. Handball players with pain had significantly greater glenohumeral internal rotation deficit, external rotation gain, and in the throwing arm in comparison to the players without pain. Side-to-side comparisons (dominant versus non-dominant) exhibited a significant difference in the two groups regarding internal and external rotation, but differences within the group with pain were greater. Greater glenohumeral rotational deficits in throwing shoulders of handball players seem to correlate with shoulder pain and internal impingement, while increased external rotation correlates with partial rotator cuff tears [14].

In a prospective cohort study of 206 male Norwegian elite handball players, Clarsen et al. observed that reduced total range of motion, external rotation weakness and scapular dyskinesis were risk factors for shoulder injuries [13]. However recently, the same research group published a prospective cohort study of 329 mixed-sex elite handball players where none of the previously identified risk factors were found to be associated with overuse shoulder injuries. Therefore, the role of glenohumeral internal rotation stretching, external rotation strengthening and scapular stability training in preventing overuse shoulder injuries in elite handball remains unclear for some populations [37].

14.6.4 Muscle Strength and RC (Rotator Cuff) Specific Tests

Rotator cuff muscle strength is better tested in the seated position. Supraspinatus strength and function could be assessed with the use of Jobe's test, also known as the "empty can test" [31]. The arms are elevated to the shoulder level in the scapular plane with the thumb pointing down. The examiner applies downward force, while the patient resists. The test is considered positive if weakness is present or pain is elicited (Fig. 14.5). The infraspinatus and teres minor are tested by resisted contraction in external rotation with the elbow flexed at 90°, respectively at 0° and 90° of abduction.

The lift-off test [38] is commonly used in orthopaedic examinations to assess the subscapularis. The patient is asked to place its hand behind its back, and is then instructed to lift off the arm in full internal rotation while the examiner applies resistance. With the internal rotation lag sign, which is a modified lift-off test, the examiner holds the hand in full internal rotation in the lift-off position. If the patient is not able to hold the arm in this position, the test is considered positive. The subscapularis can be tested also using the belly-press test (abdominal compression with elbows forward) and the bear-hug test (the patient's hand is placed on the opposite shoulder with the elbow anterior to the body. The examiner applies external rotation force, while the patient attempts to resist and maintain his hand on the shoulder) [39].

In handball players, apart from the common clinical tests to assess the cuff tendons, the rotational strength must be evaluated, especially, the external rotation, as it may be a risk factor for injuries [30, 37].

14.6.5 Subacromial and Subcoracoid Impingement

While subacromial impingement is frequent in the general population, it is less common in the dominant shoulder of handball players who more often present with internal impingement. The two most commonly used tests for subacromial impingement are the Hawkins-Kennedy and Neer tests [40].

There are some controversies regarding subcoracoid impingement and its contribution to shoulder pain in athletic population [41].

14.6.6 Superior Labrum Anterior to Posterior Lesion (SLAP)

SLAP lesions are common in the handball population, especially in those who have been playing for many years. SLAP lesions are thought to be

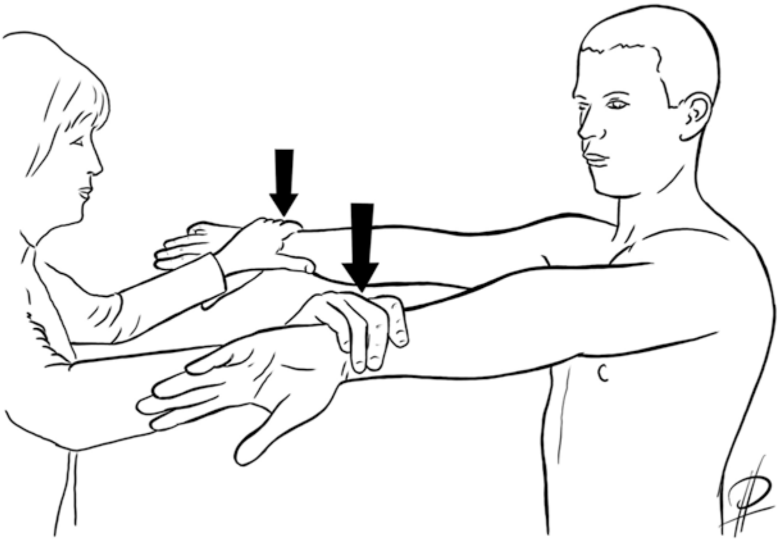


Fig. 14.5 Jobe's test

the result of the "peel-back mechanism" by which there is excessive strain placed on the bicipital-labral complex during the late-cocking phase of throwing [42]. Throwers who have SLAP tears are frequently complaining of posterior pain during palpation of the glenohumeral joint, and pain is provoked by abduction and external rotation. They may also complain of intra-articular clicking during the throwing motion, usually in the late-cocking phase and can report loss of velocity and strength. A variety of tests have been described to diagnose SLAP tears. These tests have shown variable sensitivity and specificity in the literature.

The O'Brien (active compression) test is performed while the patient is seated (Fig. 14.6). The tested shoulder is placed in forward elevation of 90° and slightly adducted in 15° [43]. The elbow is in full extension and the forearm fully pronated (with the thumb orientated down). The examiner applies a downward force, while the patient attempts to resist (Fig. 14.6). The same test is repeated with the forearm in full supination. The test is considered positive for a SLAP tear if the patient reports increased pain with the thumb down compared to the test with the palm facing up.

The anterior slide test was originally described by Kibler [44]. The test is performed with the patient seated with his hand placed on the ipsilateral iliac crest and thumb facing posteriorly. The examiner applies superior- and anterior-directed force on the elbow with one hand while stabilising the shoulder with the other hand (Fig. 14.7). If this motion produces pain or clicking sensation, the test is considered positive.

The crank test is performed with the patient in a supine position with the humerus elevated at 160° in the scapular plane. The examiner applies axial load and compression on the humerus towards the glenoid while simultaneously rotating the humerus. The test is positive if the patient reports shoulder pain or clicking [45].

14.6.7 Internal Impingement

Internal impingement is tested by placing the patient in a supine position with the arm in 90° of abduction and full external rotation. Forced abduction and external rotation provokes pain that is relieved by the relocation manoeuvre. A sensation of apprehension or impending dislocation by the patient may raise suspicion for anterior shoulder instability.

Meister [1] described the "posterior impingement sign" for the diagnosis of internal impingement. The test is performed with the throwing shoulder in 90° of abduction and maximum external rotation, which is intended to reproduce the late-cocking position, while the examiner palpates the posterior glenohumeral joint. Reproduction of pain is considered as a positive test for partial thickness rotator cuff tear and/or posterosuperior labral injury.

14.6.8 Long Head of Biceps (LHB)

In addition to SLAP tears, the biceps itself can be a pain generator and even contribute to subtle instability, especially when there are partial thickness rotator cuff tears of the superior border of the subscapularis or anterior border of the supraspinatus. These lesions are often combined with rotator interval pathology and can create some instability of the biceps. Biceps pathology can also generate loss of strength and velocity during the throwing motion. The biceps itself can be tender during the palpation as mentioned previously.

The Yergason's test is commonly used to determine pathology in the biceps tendon. The test is performed with the patient's elbow flexed to 90° and the forearm in a slightly pronated position with the upper arm on the side. The patient is asked to supinate the forearm, while the examiner applies resistance. The test is considered positive if this manoeuvre reproduces pain in the bicipital groove area [46].

The speed test is performed with the patient in a seated position. The shoulder is placed in forward elevation at 90° with the elbow extended and the forearm fully supinated. The patient is asked to resist while downward force is applied by the examiner. The test is considered positive if this manoeuvre reproduces anterior shoulder pain [47].

Fig. 14.6 The O'Brien (active compression) test

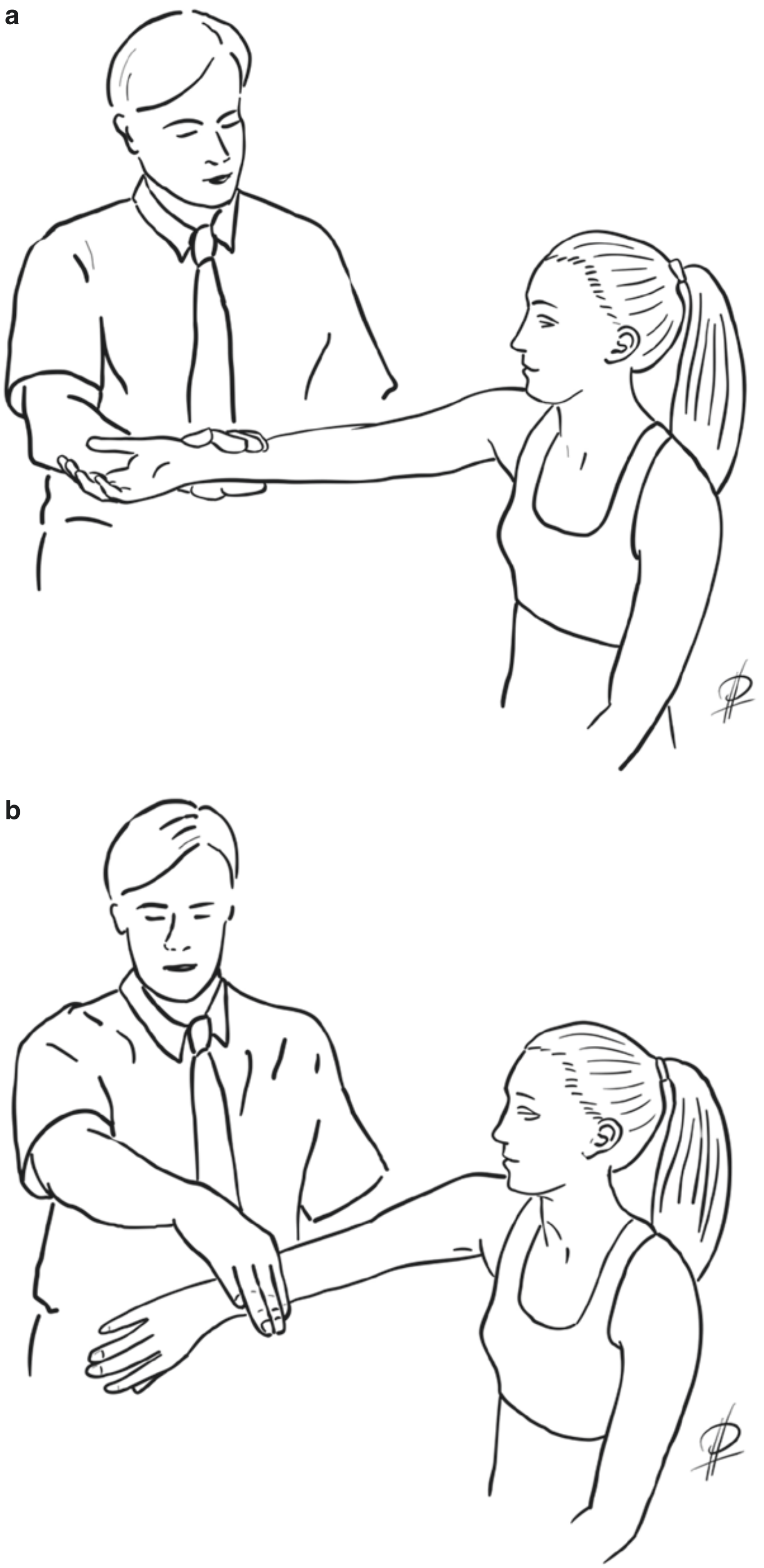
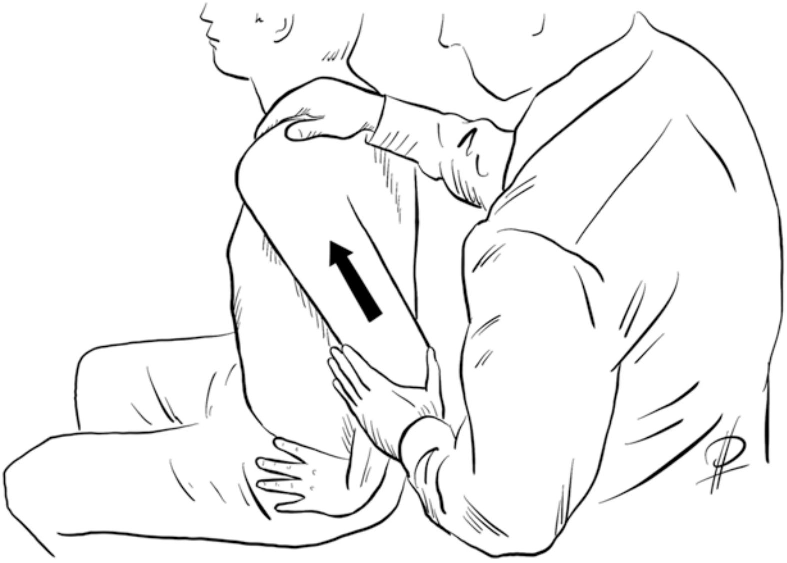


Fig. 14.7 The anterior slide test



The uppercut manoeuvre is performed with the patient's elbow on the side flexed at 90° with his hand in a fist form. The examiner grabs over the patient's fist and resists to an active uppercut motion, while the hand is brought up to the chin. A painful anterior pop in the shoulder makes this test positive. A recent systematic review [46] has shown that a combination of the uppercut test along with biceps groove tenderness to palpation have the highest sensitivity and specificity of known physical examination manoeuvres to aid in the diagnosis of LHB pathology.

Fact Box

Internal impingement, partial rotator cuff tears, labral lesions (SLAP, posterior or anterior labrum) and scapular dyskinesis are the most frequent pathologic patterns seen in shoulders of handball players.

14.7 Imaging

Routine standard radiographic views including AP view in neutral, external and internal rotation, axial view and outlet views allow visualisation of the glenohumeral joint, subacromial space, as well as bone quality, especially bony changes on the greater tuberosity. Usually, more comprehensive imaging assessment is done by using MRI scan and especially MRI arthrogram (MRA) as the presence of contrast allows superior detection of subtle tendon, capsular and labral pathologies. Additional sequences in the ABER view may improve the accuracy of the exploration, especially of the supraspinatus tendon, and are useful in assessment for internal impingement. Alternatively, CT arthrogram may be used, providing not only good soft tissue imaging using contrast (although not as detailed and as good as with MRA) but also providing the added value of optimal bony assessment.

In handball players' shoulders, common MRI findings include partial tears and tendinopathy of the supraspinatus, infraspinatus and subscapularis, degeneration and tearing of the posterosuperior glenoid labrum, superolateral humeral head defects cysts and oedema, SLAP lesions and sometimes anteroinferior labrum abnormality. Ultrasound scan may also be a valuable option in the hand of an experienced diagnostician. It may reveal focal inflammation and tendinopathy and help identify internal impingement of the shoulder.

Fact Box

There is a poor correlation between symptoms and abnormalities seen on shoulder MRI of handball players; therefore, prudence must be made in the interpretation of these abnormalities and the therapeutic decision.

14.7.1 Imaging Changes in Dominant Handball Shoulders

Jost et al. [48] compared the shoulders of 30 competitive professional handball players to 20 dominant shoulders of randomly selected volunteers. They defined three groups: Group 1, the athlete's throwing shoulder which showed an average of seven abnormal MRI findings per shoulder; Group 2, the athlete's non-throwing shoulder which showed an average of four abnormal findings per shoulder; and Group 3, the dominant shoulder of volunteers which showed an average of two abnormal findings. They found abnormal MRI findings in handball players; the majority of them were related to cuff pathology, posterosuperior impingement and SLAP lesions. Partial rotator cuff tears and superolateral osteochondral defects of the humeral head were identified as typical throwing lesions. Partial rotator cuff tears were most prevalent in the supraspinatus tendon (43%) but also in the infraspinatus (27%) and subscapularis (17%). Jost et al. reported a significant number of findings correlating with posterosuperior glenoid impingement, especially superolateral osteochondral lesions of the humeral head evident in 57% of the handball players' throwing shoulders. Although somewhat similar in appearance to Hill-Sachs lesions observed in anterior shoulder instability, superolateral osteochondral lesions are considered a different entity.

In our personal experience, we have found a number of cases of Bennett lesions in the handball population [49]. This lesion was defined as an ossification of the posterior band of the inferior glenohumeral ligament (IGHL) as a result of an extra-articular posterior capsular avulsion injury. It was initially described in baseball pitchers (Fig. 14.8a–d).

In the study by Jost et al., although 93% of the throwing shoulders had abnormal MRI findings, and average of seven abnormal MRI findings per shoulder, only 37% were symptomatic. The symptomatic throwing shoulders did not have more rotator cuff abnormalities than pain-free asymptomatic shoulders. One-third of the throwing shoulders had findings correlating with posterosuperior impingement, and 45% were completely asymptomatic. This study concluded that there is a poor correlation between symptoms and abnormalities seen on MRI. This emphasises one of the difficulties in managing the handball population in terms of finding's interpretation and symptoms, and it is still not entirely clear whether these abnormalities are pathologic or adaptive.

Therefore, prudence must be made in the interpretation of these abnormalities and their management, especially when it comes to surgical decision-making, and it must never rely only on the imaging assessment.

These MRI findings have been observed in other throwing sports like baseball or tennis [50].

14.8 Conservative Treatment

Conservative management is usually the first (and last) line of treatment for shoulder pathologies in handball players. This correlates with the approach in other overhead throwing sports. A phased progression of rehabilitation has been suggested for the nonoperative management of overhead throwing athletes [29]. This protocol must be customised to the patient's pathology and can be sometimes be modified during the rehabilitation process as symptoms can change during the treatment.

In phase 1 or the acute phase, the objective is to allow healing of the injured tissue, decrease pain and inflammation, normalisation of ROM deficit, passive ROM and active-assisted exercises combined with massage therapy, manual drainage and stabilisation exercise, pain killers and Nonsteroidal Anti-Inflammatory Drugs.

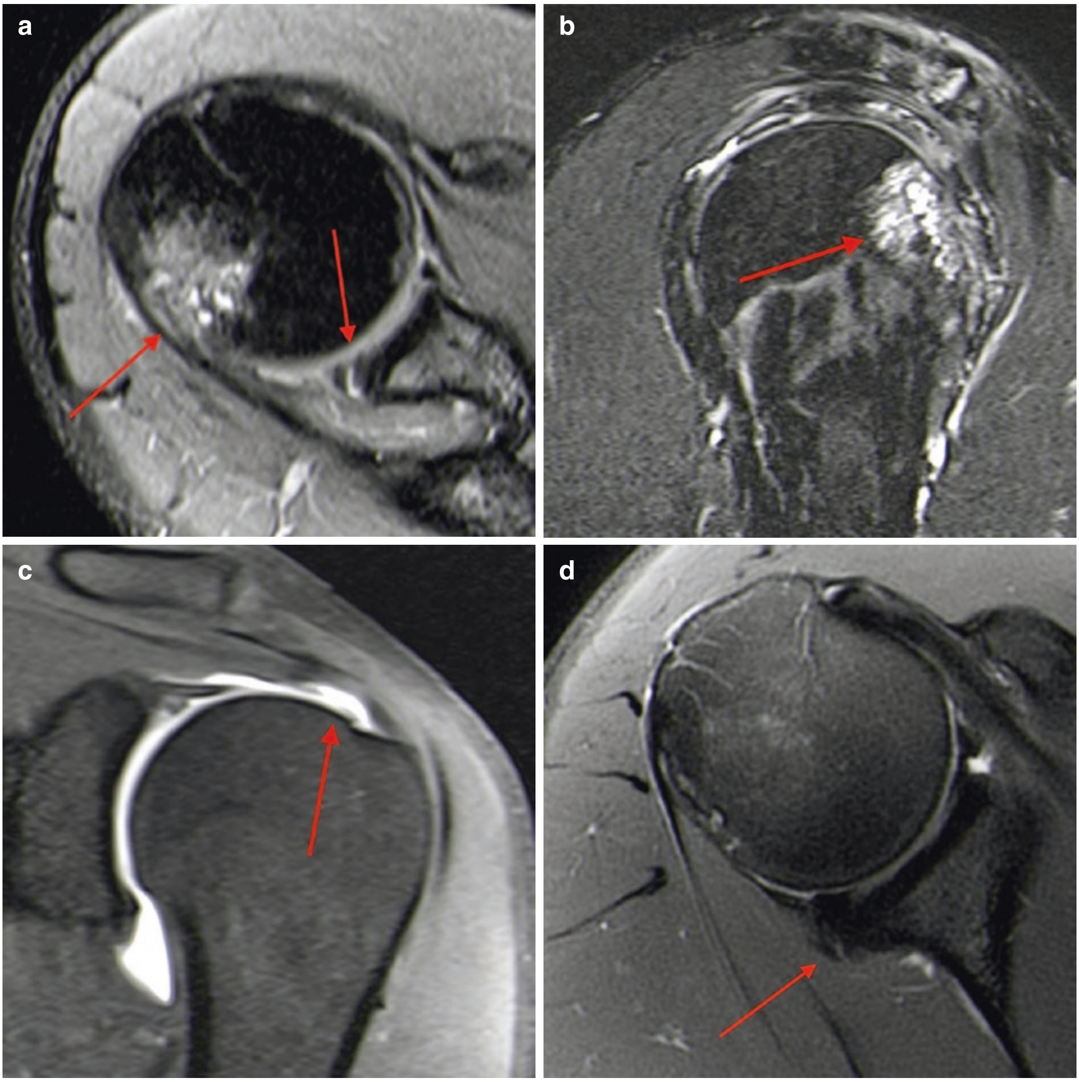


Fig. 14.8 (**a**, **b**) Superolateral humeral head defects, cysts and oedema, posterosuperior glenoid labrum lesion. (**c**) PASTA lesion: Partial articular supraspinatus tendon avulsion. (**d**) Bennett lesion: Mineralisation of the posterior band of the inferior glenohumeral ligament

In phase 2, after pain and inflammation reduction, gentle stretching, neuromuscular exercises and strengthening can be applied. Muscle contractures must be addressed at this stage if present [32]. Different stretch exercises are recommended like the classical "sleeper stretch" (Fig. 14.9a). The athlete lies on the involved side with the shoulder in 90° of forward elevation. The opposite arm internally rotates the pathologic shoulder to stretch the posterior aspect of the joint. Another way to treat the posterior retraction is the "cross-body stretch" where the patient places the involved shoulder against a wall to avoid any scapular rotation, the opposite arm pulls the involved arm across the body, stretching the posterior aspect of the shoulder (Fig. 14.9b).

Customised strengthening programme should be applied at this stage based on the areas of weakness noted during the physical examination. Isokinetic testing can identify any ratio deficits before the athlete is allowed to return to play. The

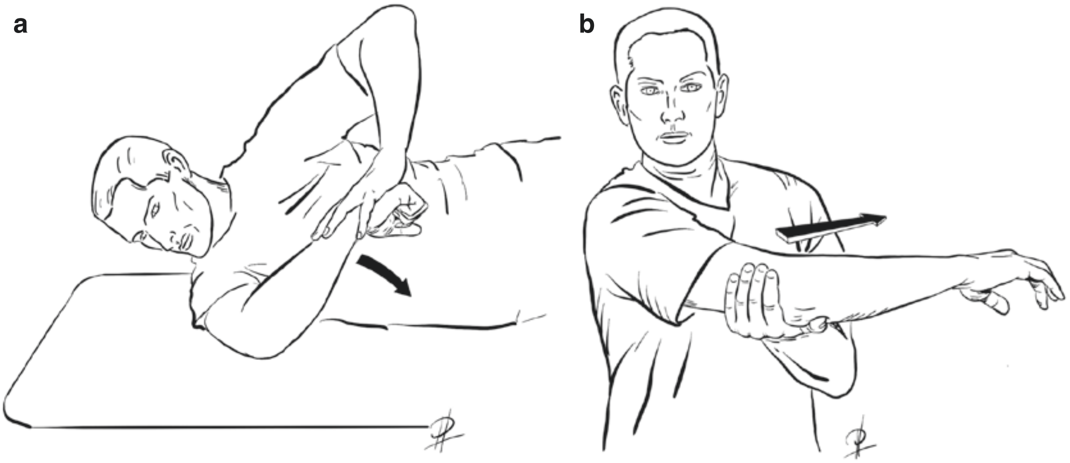


Fig. 14.9 (**a**) Sleeper stretch. (**b**) Cross-body stretch

external rotation strength has been found to be 65% of internal rotation strength in 90/90 position during assessment of the strength norms and ratios for throwing athletes using isokinetic dynamometry [51].

The patient moves to phase 3 when he demonstrates a very low ROM deficit, almost no cuff weakness, good neuromuscular control and almost no pain during testing. At this phase the patient can start intensive strengthening and endurance exercises, introduce plyometric training and start throwing exercises.

In phase 4, the patient continues with strengthening and neuromuscular exercises, as well as advanced interval throwing [51]. The goal is to progressively return to normal throwing with gradual high velocity recovery.

If there is no improvement after 3 months or if the athlete has no ability to return to competitive level sports within 6 months, this prompts re-evaluation, and more aggressive approaches, such as surgery, could be considered.

Fact Box
The most common treatment strategy for shoulder injuries in handball is conservative, but surgery may be indicated in some specific cases.

14.9 Management and Decision-Making in Common Shoulder Pathologies in Handball

This section discusses several common shoulder pathological conditions and various treatment options. Some of the common pathologies seen in shoulders of handball players may occur in combination, and their management and decision-making should depend on a variety of factors such as the assessment, symptom duration, the players' specific playing role (i.e. back and wing players throw more; back and line players sustain more contact), timing during the season and, when applicable, response to previous treatments.

14.9.1 Internal Impingement

Posterior or internal shoulder impingement was defined in 1992 by Walch [50] who assessed 30 athletes with shoulder pain, 17 of whom underwent an arthroscopic shoulder examination. The typical findings of this study included posterior labral lesions, articular surface rotator cuff tears and the absence of Bankart lesions. In all cases an obvious sign of impingement of the posterior aspect of the humeral head on the posterosuperior rim of the glenoid was observed, with corresponding lesions when the arm was brought into the abducted, externally rotated throwing position (ABER).

Almost simultaneously, in 1992, Jobe [52] reported similar arthroscopic and MRI findings, but he hypothesised that the process of internal impingement or posterior shoulder impingement was related to subtle anterior shoulder instability or "micro instability". Later on, different theories were developed to explain the internal impingement. Burkhart et al. [34] described the concept known as the "pathological cascade" of the throwing shoulder which begins with GIRD secondary to posteroinferior capsular contracture. This posterior contracture creates posterosuperior shift of the glenohumeral centre of rotation which could explain the internal impingement. Some authors have attributed the posterior shoulder soft tissue tightness to the repetitive deceleration phase of the throwing motion [34]. Repetitive internal impingement can lead to PASTA lesion (partial articular supraspinatus tendon avulsion) which sometimes can be significant.

Lower incidence rate of anterior shoulder instability has been observed in athlete population who participate in activities requiring repetitive external rotation abduction. This is quite surprising as the abduction external rotation is commonly a cause for anterior shoulder dislocation in the general population. Halbrecht [53] found that patients with subluxation or frank dislocation are not affected by internal impingement. In fact, it is still unknown whether anterior shoulder instability could "protect" from internal impingement or if the internal impingement could protect from anterior subluxation or recurrent instability. Today, there is still controversy over the explanation of this low rate of anterior shoulder instability in the handball players. The thickening of some parts of the shoulder capsule or adaptations in shoulder rotation motion have been proposed as possible explanations. This highlights again the fact that we still have a lot to learn about the pathogenesis in handball and the throwing shoulder.

14.9.2 Rotator Cuff Tears

Articular side partial thickness rotator cuff tears is a common finding in the dominant shoulders of handball players. These lesions are usually at the junction of the supraspinatus and infraspinatus tendon insertion [50]. The lesion can be the consequence of repetitive compression during internal impingement. Some authors believe it can be the result of a tensile repetitive overload and micro trauma in eccentric activation [34]. A tear in the superior fibres of the subscapularis tendon may result in subtle destabilisation of the biceps tendon in the proximal part of the bicipital groove which may lead to anterior pain and mechanical symptoms such as snapping or locking of the joint [19]. Full thickness rotator cuff tears are rarely seen in overhead throwers in general, and this seems to be the case in handball as well.

The treatment of partial thickness rotator cuff tears depends on different factors including the size and depth of the tear, location, quality of the tendon and muscle as well as the patient's profile. Nonoperative treatment should be the initial course of management. However, if no improvement is achieved after several months of conservative treatment, surgery can be considered. The patient's expectations as well the phase in his/her career and timing during the season must be taken into consideration when surgery is indicated.

It is generally accepted that, when surgery is indicated for partial rotator cuff tears in the general population, repair is performed if the tear involves more than 50% in thickness and simple debridement when the rupture involves less than 50% [54]. However, in the throwing shoulder population, surgery should be considered if the partial tear involves between 50% and 75% thickness. Partial tears of the cuff below 50% of thickness are frequent and can be managed conservatively [55]. Simple debridement has been shown not as successful with low rates of return to sport in the throwing athlete population [56]. Although rare, full thickness rotator cuff tears have poor prognosis even when they are surgically repaired. Not more than half of the handball players are able to return to play at their pre-injury level [57].

14.9.3 SLAP Lesion

Four types of SLAP injuries were initially described by Snyder [58]. Type I (fraying lesion), type II (labral fraying with detached biceps tendon), type III (bucket-handle tear of the superior labrum) and type IV (displaced bucket-handle labral tear with extension into the biceps tendon root). The repetitive external rotation of the throwing shoulder could be a cause for a SLAP lesion. Burkhart and Morgan have hypothesised the "peel-back mechanism" that produces the SLAP lesion in the overhead athlete [42]. The LHB could be a dynamic restraint to external rotation when the arm is abducted.

There is no scientific support to justify surgical debridement for SLAP I lesions. There is some controversy about the surgical indications for SLAP type II. SLAP type III and IV in overhead athletes, where there is a "bucket-handle" tear and extension of the lesion into the biceps, clearly requires surgical management, most commonly a repair. Biceps tenodesis (detachment of the long head of biceps tendon from its insertion to the labrum and reinsertion to the humeral head) could be another reasonable option for athletes requiring surgery for a SLAP lesion [59]. The optimal treatment is still uncertain as a recent study concluded that neither labral repair nor biceps tenodesis had any significant clinical benefit over sham surgery for 118 patients who had an isolated SLAP II lesion [60].

As with any other intra-articular lesion in the throwing shoulder, when a SLAP has been identified using imaging studies, the decision to perform surgery should be taken after careful assessment of the symptomatology and failure of appropriate conservative treatment.

14.9.4 Scapular Dyskinesis

Scapular dyskinesis is believed to be very common in throwing athletes in general and handball players in particular, and is recognised as a cause for shoulder pain and dysfunction. Burn found that the scapular dyskinesia has a greater reported prevalence in the overhead athlete (61%) compared with the non-overhead athlete (33%) and in as high as 67–100% in athletes with shoulder injury [61]. Priest and Nagel [62] were the first to describe this abnormality as "shoulder depression" and originally named it "tennis shoulder" in 1976. Later on, Burkhart and colleagues [34] described the SICK scapula (scapula malposition, inferior medial border prominence, coracoid pain and malposition, dyskinesia of scapular movement) syndrome. It is still unclear whether scapular dyskinesis (SICK scapula) is a primary disorder or a secondary phenomena caused by abnormal shoulder biomechanics. Some studies have shown that the shoulder pain can be the consequence of functional tightening of the upper trapezius and pectoralis minor combined with inhibition of the lower trapezius and serratus anterior [32], and this could explain the tenderness over the coracoid insertion of the pectoralis minor. In throwing athletes, this biomechanical dysfunction may lead to scapular impingement onto the thorax during the late-cocking phase of throwing [63].

As already mentioned, the scapula is a crucial link in the kinetic chain between the energy produced by the lower and upper extremity and the ball. Therefore, any scapular destabilisation will result in elevated stress at the glenohumeral and scapulothoracic joint [64]. Thorough assessment of the scapula in behaviour and position during clinical examination, including throwing movements, is imperative in handball players before initiating any treatment.

Scapular dyskinesis has a high prevalence in handball shoulders and can entail risk for secondary shoulder pathologies [13]. Moreover, handball players with scapular dyskinesis have been shown to be at a higher risk for shoulder injuries even with a moderate training load increase of 20–60% over 1 week (compared to the average load in the preceding 4 weeks) [30]. Therefore, the clinical examiner should be vigilant in recognising the shoulder at risk in this population [65]. Athletes with scapular dyskinesis should be identified as early as possible during the preseason and closely observed by the medical team. Prevention measures have been shown to reduce the prevalence of shoulder problems, especially in elite handball players, and should be included as part of the warm-up routine [66].

Although conservative treatment and prevention measures can be successful in management of scapular dysfunction, some players may develop scapular bursitis or snapping scapula. The excision of pathologic tissues at the inferior margin of the scapula has demonstrated good outcomes in selected patient populations and may be considered in rare persistent cases [63, 67].

14.10 Summary

Handball is a high intensity sport with frequent physical contact. Although traumatic injuries to the shoulder are very common in handball, it is also probably the most common site for overuse injuries in handball and a major reason potentially affecting players' performance. Internal impingement is a common pathology in dominant shoulder of handball players; however, there is still some controversy regarding the underlying pathology in this population, especially concerning the low rates of anterior instability. Conservative treatment should be the first line of treatment, and considerable efforts should be made towards prevention. Preventive measures have been shown to reduce the prevalence of shoulder problems, especially in elite handball players, and should be included as part of the warm-up routine.

Scapular dyskinesis may have been underestimated in the past in overhead throwers in general and handball players in particular. Specific programs to correct the scapular imbalance, combined with stretching and strengthening programs, have been developed recently and provided promising results. Close attention should be given also to ER strength assessment and ER:IR strength ratio. External rotation strengthening should be targeted and recommended when weakness is detected.

The throwing shoulder in handball players may present with anatomical adaptations and pathologies which do not always correlate with the symptoms. Therefore, the decision for management, and especially surgical management, must be cautiously debated after consideration of the history of symptoms, physical examination, imaging assessment, anatomic-clinical correlation, efficiency of conservative treatment, patient expectations and the athlete's career.

Fact Box
Prevention programs have shown to be effective in reducing the prevalence of shoulder injuries in handball.

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15 Shoulder Instability in Handball Players

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15.1 Introduction

Overhead throwing athletes in general and handball players in particular are at risk for shoulder injuries as a result of the high forces sustained by the shoulder during the throwing motion. The glenohumeral joint is formed by an articulation between the humeral head and a relatively small glenoid fossa, allowing a wide range of shoulder movements, however also making it the most commonly dislocated joint in the body. Dynamic stabilizers of the glenohumeral joint include the rotator cuff, the scapulothoracic muscles, and the long head of the biceps tendon. Static stabilizers include the osseous anatomy, the fibrocartilaginous labrum, and the glenohumeral joint capsule. In overhead throwing athletes, while a single traumatic event may result in instability, more commonly it is repetitive overload that leads to failure of one or more of these structures and as a result—to laxity. The throwing action requires a coordinated motion that involves the entire body and has been previously defined as the "kinetic chain" [1]. A well-timed sequential muscle activity is required to produce an effective kinetic chain and transfer energy generated in the lower body to the upper body through the shoulder, arm, hand, and fingers and finally to the ball [2]. Body position, trunk rotation, and positioning of the scapula are key elements in the kinetic chain, and therefore any physical condition that alters the components of the kinetic chain may result in the development of a dysfunctional shoulder [1]. There is a delicate balance between shoulder mobility and stability in elite-level overhead throwing athletes. In fact, the term "the thrower's paradox" was coined as a result of the need for the shoulder to maintain sufficient mobility to reach extreme positions of rotation to generate ball velocity while maintaining joint stability at the same time [3]. The demands and repetition of high-velocity overhead throwing can alter this stability-mobility relationship and ultimately lead to injury. Stability of the shoulder is maintained by the abovementioned passive and active stabilizers. In the absence of other forces, the torques on the glenohumeral joint are balanced.

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Fig. 15.1 The attacker's shoulder is often strained by the defender by charging the arm during shot attempts (Photos courtesy of Lothar Gudat. Used with permission). From Laver and Myklebust [11], used with permission

With each throw, the soft-tissue envelope surrounding the shoulder is loaded at levels that approach its ultimate failure loads, thus making it vulnerable to injury. While the majority of data on injury patterns and mechanisms in the shoulders of high-level overhead throwers are from studies focusing on baseball pitchers [4–8], handball players are different as the handball throwing motion has additional complex features that may impact potential pathologies in the shoulder [9]. Handball is not only an overhead throwing sport but also a contact sport where players commonly encounter upper extremity and/or body contact during and/or at the end of the throwing action. This contact is unpredictable and may expose the shoulder to additional loads in different directions. Handball players perform up to 48,000 throws per year [10], and considering that the throwing arm is frequently and unexpectedly opposed or blocked by an opponent, causing repetitive microtrauma to the capsulolabral structures of the shoulder, it is not surprising to see that most of the acute shoulder injuries occur to players who throw most (backcourt and wing players) [11]. The forces encountered by a player's shoulder affect the joint, especially during the cocking phase of the throw. In addition, the defense often strains the shoulder by charging the arm (Fig. 15.1).

Many players also sustain an additional impact on the shoulder as they block contact with the ground/floor as this is also an integral part of the game and even throwing technique, mainly for line and wing players. In addition, handball players are often exposed to upper extremity contact during other actions within the game (defensive as well as offensive) which may stress their shoulders beyond the end range of motion, thus increasing the risk of potential instability (Fig. 15.2a, b). These unique features of the game make the kinetic chain in handball less predictable and as such give handball players less or no time to biomechanically adjust.

In an attempt to characterize shoulder pathology in handball players, Jost et al. evaluated the shoulders of 30 fully competitive professional handball players and 20 randomly selected volunteers using magnetic resonance imaging and correlated imaging and clinical findings. Abnormal MRI findings were found in 93% of the throwing shoulders, but only 37% of the shoulders were symptomatic. Typical asymptomatic MRI findings included tendinopathies and

Fig. 15.2 (**a**, **b**) Contact situations during the game stressing the shoulder at end range of motion

partial rotator cuff tears, posterosuperior glenoid impingement, and impressive superolateral osteochondral defects of the humeral head; 71% of the throwing shoulders with osteochondral defects were asymptomatic [12].

Further understanding of the biomechanics and kinematics of throwing in handball, both normal and pathologic, may assist clinicians to develop effective prevention, treatment, and rehabilitation strategies for this population. The purpose of this chapter is to explore the issue of instability in handball players and provide an information basis to assist with evaluation and treatment of shoulder instability in handball players.

Fact Box
Laxity findings are common in handball players but do not require surgical treatment.

15.2 Epidemiology

Very few descriptions exist on instability features in handball players.

Myklebust et al. evaluated the prevalence and consequences of shoulder pain problems among Norwegian female elite handball players (179 players from all 12 teams of the Norwegian elite league) [13]. Fifty-seven percent of all players reported previous or current shoulder pain at the time of evaluation of which 36% (*n* = 65) reported current shoulder pain upon evaluation and 22% (*n* = 40) reported previous shoulder pain. Positive apprehension and relocation tests were recorded by 29% (*n* = 51) of all players and among 60% of players with pain at the time of evaluation.

15.3 Pathophysiological, Anatomical, and Biomechanical Considerations

The term "instability" constitutes a spectrum of disorders which includes hyperlaxity, subluxation, and dislocation. Principally, glenohumeral instability can be classified according to its etiology, degree, frequency, and direction. The classic classification by Thomas and Matsen categorized affected individuals into two groups with traumatic and atraumatic instability represented by the mnemonics TUBS (traumatic, unidirectional, Bankart lesion, surgery), and AMBRII (atraumatic, multidirectional, bilateral, rehabilitation, inferior capsular shift, interval closure) [14] has been supplemented by a further group that is mainly comprised of overhead athletes with so-called minor or microinstability and that has been labelled with the acronym AIOS (acquired, instability, overstress, surgery) [15]. However, it should be emphasized that the spectrum of congenital or acquired hyperlaxity, microinstability, and traumatic instability can overlap particularly in athletes engaged in overhead sports.

As previously mentioned the glenohumeral joint is formed by an articulation between the humeral head and a relatively small glenoid fossa, allowing a wide range of shoulder movement, however also making it the most commonly dislocated joint in the body. Dynamic stabilizers of the glenohumeral joint include the rotator cuff, the scapula-thoracic muscles, and the long head of the biceps tendon. Static stabilizers include the osseous anatomy, the fibrocartilaginous labrum, and the glenohumeral joint capsule. The capsulolabral complex, especially the inferior glenohumeral ligament (IGHL), is considered the main static stabilizer of the shoulder joint at the extremes of passive range of motion [16, 17]. Any injury or abnormality of the static stabilizers such as anteroinferior capsulolabral lesions, cartilage damage, or bony lesions may lead to glenoid depth loss and decreased joint congruency resulting in decreased stability [18]. Especially the importance of bony glenoid lesions have been demonstrated in cadaveric and biomechanical investigations, reporting that glenoid deficiency has an important contribution to recurrent shoulder instability [18–20].

The repetitive nature of the throwing action as well as the high forces generated and sustained by the shoulder joint can lead to both bony and soft-tissue adaptive changes of the dominant extremity [21–23]. The total arc of motion, ranging from maximal internal to maximal external rotation of the arm in the abducted position, is typically around 180° in healthy individuals [3] (Fig. 15.3).

A possible explanation is that the increase in external rotation is caused by an adaptive increase in humeral retroversion in overhead throwers and that any significant internal rotation deficit (>20°) is therefore a result of soft-tissue adaptations. An

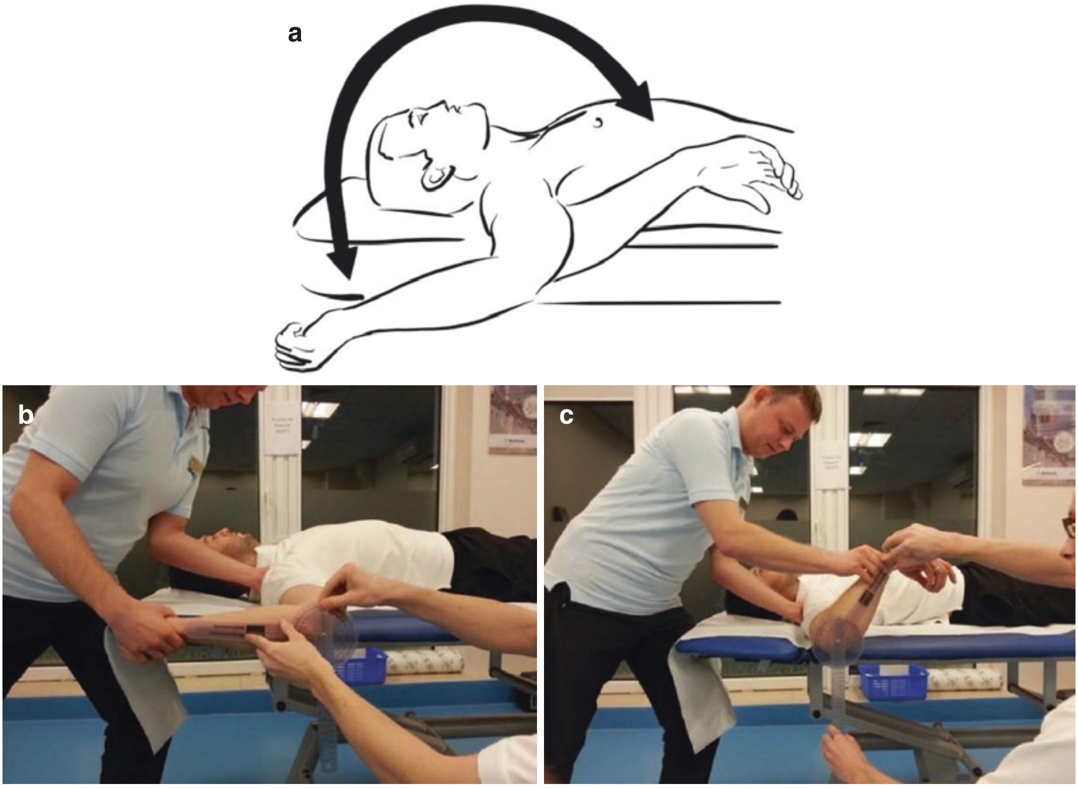

Fig. 15.3 (**a**–**c**) The arc of motion of the dominant arm of asymptomatic elite-level throwing athletes is typically shifted posteriorly, with increased external rotation and decreased internal rotation of the abducted shoulder [24]

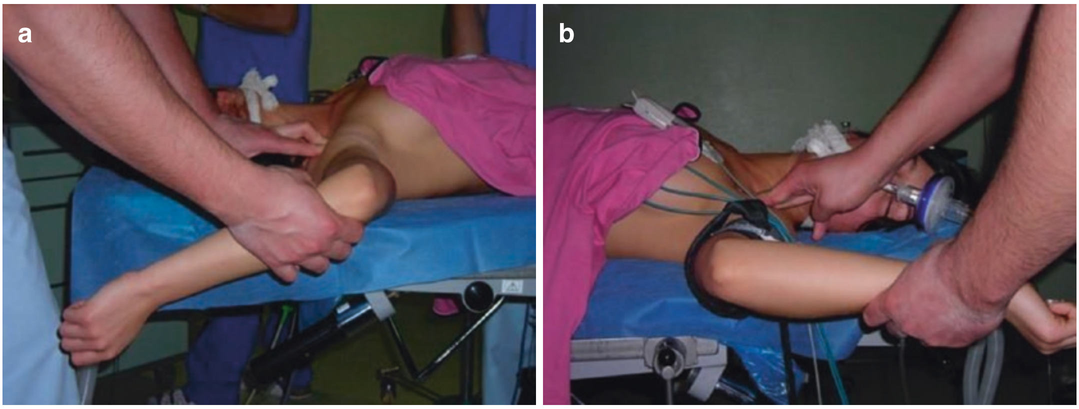

Fig. 15.4 Increased ER in the dominant shoulder (examination under anesthesia) (**a**) compared to the non-dominant shoulder (**b**)

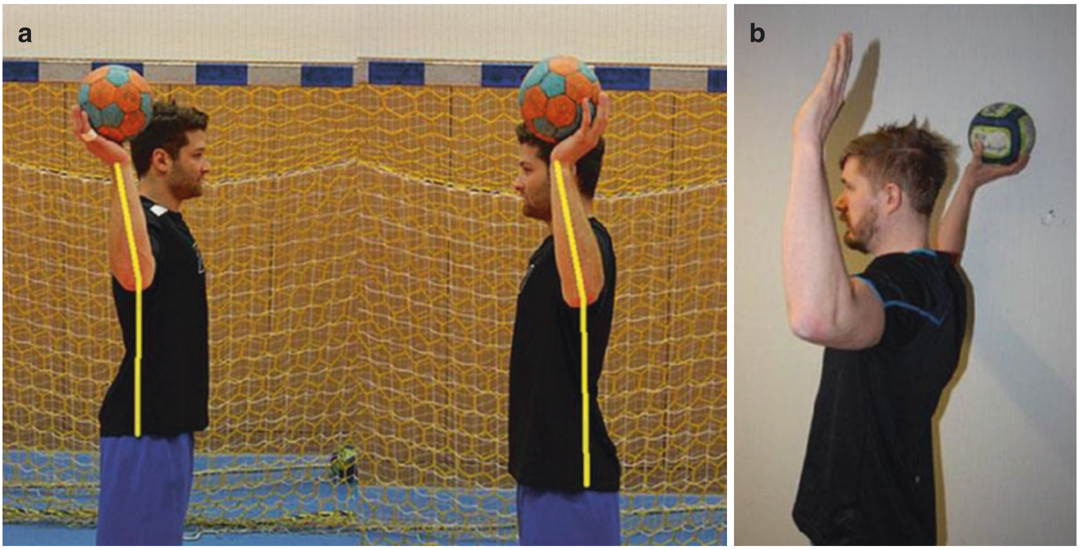

Fig. 15.5 Increased external rotation (ER) in the dominant shoulder (Rt.) compared to the non-dominant side (Lt.) in an elite professional-level handball player (**a**) and an amateur-level player (**b**). It is important to note that these differences are accentuated during a throwing action (during the cocking phase) (Photos courtesy of Chen Pomeranz (**a**) and Grethe Myklebust (**b**). Used with permission)

increase in maximal external shoulder rotation of about 10–15° in the throwing arm of handball players can be found in the majority of players, compared to the non-dominant side (Figs. 15.4a, b and 15.5).

Anterior laxity due to chronic overuse (i.e., stretching the joint capsule and ligaments) is a possible explanation. Pieper et al. studied the functional characteristics of shoulders of handball players [21]. In addition to the increase in external rotation, they observed a considerable reduction of maximal internal rotation of the dominant arm (Fig. 15.6a, b) [25].

Similar findings have been reported in more recent studies in handball players (at least 10° reduction of internal rotation) [26, 27] and have also been reported for athletes in unilateral overhead or throwing sports like tennis [1, 28, 29] or baseball [30, 31]. Pieper also found increased humeral retrotorsion in the throwing arm of

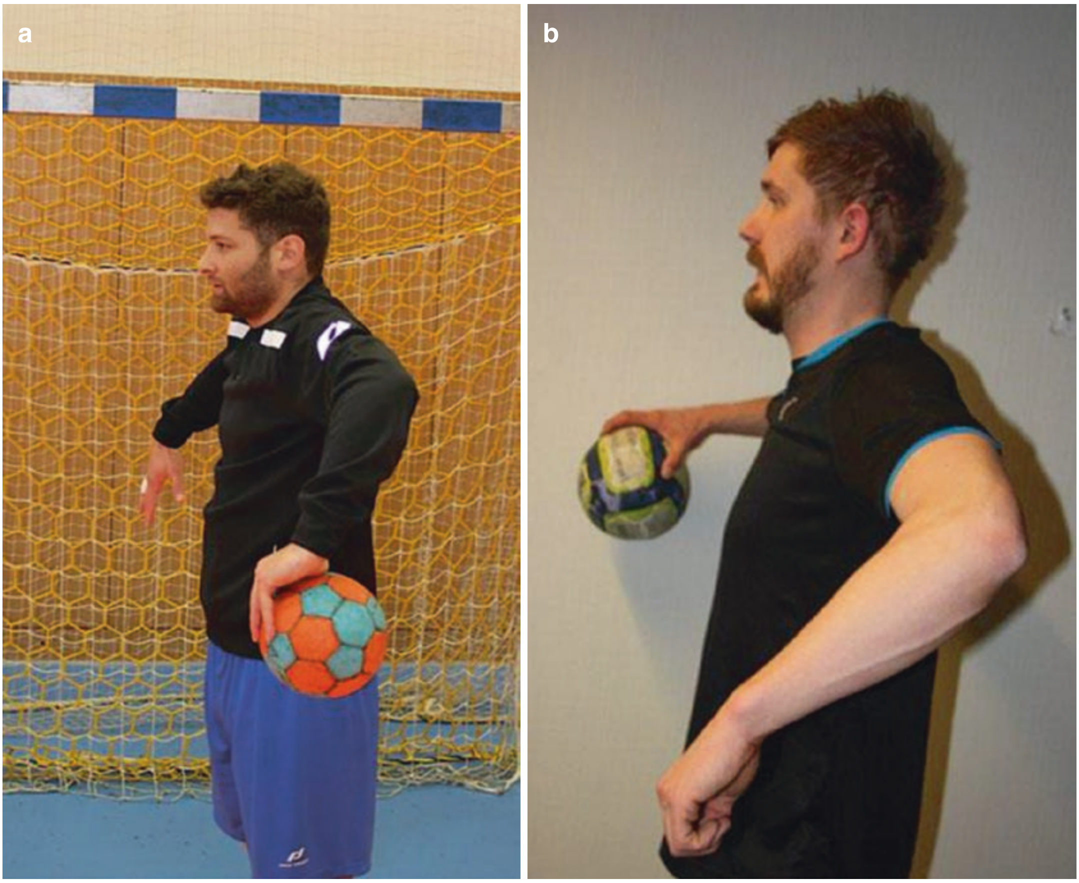

Fig. 15.6 (**a**, **b**) Reduction of maximal internal rotation of the dominant arm compared with the non-dominant arm

handball players [21]. This seems to be an adaptation to extensive external rotation in the throwing action during growth. The increased retrotorsion allows more external rotation of the shoulder before the humeral head puts excessive strain on the anterior capsulolabral complex, potentially leading to anterior shoulder laxity. Players who fail to adapt in this manner seem to sustain more strain on their anterior capsule at less external rotation and may thus be at higher risk to develop anterior laxity and chronic shoulder pain. Interestingly, there might me be a strong association between a decreased total arc of motion, decreased shoulder strength, and GIRD [32]. Therefore, not all GIRDs are prone to develop instability.

It is still unclear whether these torsional changes correlate with the starting age of playing handball, the intensity of training and competition, the hours of exposure, or an interaction of these factors. In addition to osseous adaptations, there are soft-tissue adaptations that contribute to joint mobility. For example, baseball pitchers commonly demonstrate an increased sulcus sign on physical examination [33], and an excessive sulcus sign may be caused by laxity of the coracohumeral ligament and rotator interval structures that restrain external rotation of the abducted arm [34]. Repetitive ligament stresses may also lead to microtears in the collagen fascicles and capsular laxity, which would also allow increased external rotation [34, 35].

Another factor playing an important role in regulation of shoulder instability is neuromuscular control [36]. It has been shown that proprioception of the affected shoulder was altered in patients with glenohumeral instability compared with the asymptomatic extremity and eliminated after shoulder reconstruction, suggesting that surgery restores some of the proprioceptive characteristics [37].

Fact Box
Often laxity may alter throwing biomechanics and technique – leading to other problems/injuries.

15.4 Anatomic Findings Associated with Shoulder Instability

15.4.1 Common Soft-Tissue Lesions

Bankart lesion—The Bankart lesion, considered as the "essential lesion" of anterior traumatic dislocation of the shoulder occurring in 90% of cases of anterior instability, is a detachment of the anteroinferior labrum with its attached inferior glenohumeral ligament complex (IGHLC) [38]. Although almost always present in patients with traumatic instability, it does not produce instability in isolation. The underlying cause is multifactorial, with **plastic deformation of the IGHLC** considered crucial to development of recurrent anterior instability [39]. This plastic deformation remains irreversible. This seems to be important to notice in decision-making for the treatment of shoulder instability especially in overhead and contact athletes like handball players [17].

In addition, superior labrum anterior and posterior detachment **(SLAP)** may occur in continuity with Bankart lesions and defects of the rotator interval adding to increased translation in the anteroposterior and superoinferior directions [40]. It is more common in throwing athletes perhaps due to the eccentric loads on the biceps anchor during the deceleration phase of throwing [41].

Humeral avulsion of the glenohumeral ligaments (HAGL)—Typically recognized after first-time dislocations. The lesion's location is at the humeral attachment site of the ligaments. It may occur in isolation or in conjunction with a Bankart lesion [42].

Anterior labroligamentous periosteal sleeve avulsion (ALPSA)—A similar lesion to the Bankart lesion: originally described by Perthes in 1906; however, the anterior scapular periosteum does not rupture, and the IGHLC, labrum, and periosteum are stripped and displaced in a sleeve-type fashion medial on the glenoid neck [43, 44].

15.4.2 Bony Lesions

Bony Bankart lesion—As the humeral head dislocates anteriorly, it may cause a fracture of the anteroinferior glenoid, termed a "bony Bankart lesion" (Fig. 15.7).

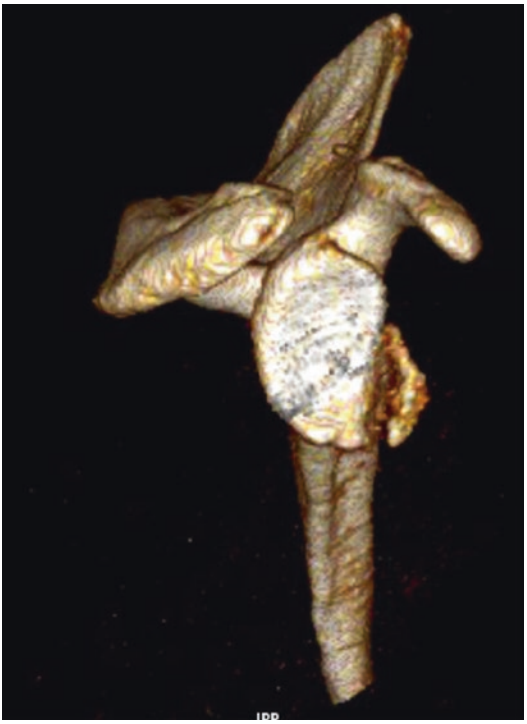

Fig. 15.7 3D CT reconstruction image of a bony Bankart lesion

This mechanism may also result in a compression fracture or wear of the glenoid rim. Anterior glenoid defects result in loss of glenoid concavity, therefore compromising the static shoulder restraints predisposing to instability [45]. Cadaveric studies report that glenoid lesions measuring more than 50% of the glenoid length reduced dislocation resistance by more than 30% and defects wider than 20% glenoid length predispose to recurrence despite Bankart repair [18, 19]. Recent studies have suggested even smaller bone deficits are prone to fail with a Bankart repair [20].

Hill-Sachs impression fracture—An impression fracture on the posterolateral aspect of the humeral head generated when the humeral head impacts on the anterior glenoid [46]. The incidence of this lesion is 90% in primary dislocation and 100% in recurrent dislocation [38]. Most lesions are small to moderate in size and do not influence shoulder stability [47]. However, Hill-Sachs lesions may contribute to recurrent instability, and therefore defects should be addressed in patients with severe defects or defects larger than 60% of the humeral head radius and in those who engage in 90° of abduction and 90° of external rotation (the 90/90 position) [48].

Bipolar lesions—Defined as presence of a bony lesion at both the glenoid and humeral head (i.e., a bony Bankart and a Hill-Sachs lesion) [49]. Shoulders with bipolar lesions are frequent in chronic instability [45] and are substantially more likely to develop persistent instability and are less likely to respond to conservative treatment [50].

15.5 Traumatic Shoulder Dislocations

The spectrum of traumatic shoulder dislocations is the most serious, and severe shoulder injury in handball players, however is not encountered often. The epidemiology of these events in handball has not been well documented, and reports on handball players are more often encountered as part of larger series of treated athletes [51, 52].

It is important to obtain detailed history to understand the exact mechanism, the applied forces and the position of the arm during the dislocation event as well as previous episodes. The player's physical examination on the court/sidelines or in the emergency room should include an accurate documentation of the neurovascular status. It is mandatory to evaluate the integrity of the axillary nerve before reduction. The sensory function of the axillary nerve's evaluation by is done by testing sensation in the lateral aspect of the shoulder and around the deltoid muscle. Axillary motor function is assessed by asking the patient to minimally abduct the elbow from the side of the body toward the examiner and evaluating for deltoid contraction. If there is a risk for major arterial injury, open reduction must be done as soon as possible [53].

We strongly do not recommend "on court" relocation maneuvers, and we prefer performing shoulder relocations after an appropriate radiographic evaluation and under optimal conditions. As most first time traumatic shoulder dislocations would most likely occur during a match or training session and therefore would be within reasonable distance from an appropriate facility, we recommend initial "in field" immobilization and safe transfer to a close medical facility for further management and to reduce the risk of complications, especially in cases of fracture-dislocations which may result often even in hemiarthroplasty [54] Table 15.1 provides recommendations for initial management of primary traumatic shoulder dislocation in handball players.

The aim is to perform a safe and controlled closed reduction manoeuver as soon as possible to avoid further damage and complications. Sedation and relaxation is not mandatory but usually necessary as the bulky musculature of players with the stress of a primary dislocation may make it difficult to achieve adequate relaxation. In rare cases, where closed reduction cannot be achieved, reduction should be performed under short general anesthesia [55]. The shoulder should be immobilized following reduction with classic immobilization in internal rotation in the majority of cases. It does not seem that different durations of immobilization improve the outcome compared to early functional treatment [56, 57]. There were initial reports that

Table 15.1 Recommendations for initial management of primary traumatic shoulder dislocation in handball players

Obtain history and mechanism	Primary or recurrent event? direction of dislocation? rule out complex traumatic mechanism which may result in fracture/fracture-dislocation
Thorough neurovascular evaluation	Mandatory to evaluate the integrity of the axillary nerve before any reduction maneuver
Immobilization (sling/brace)	For pain control and protection
Transfer to an appropriate medical center with imaging facilities	
Radiographic evaluation in at least 2 planes before and after the reduction maneuver	X-ray views: true anteroposterior (Grashey) view, trans-scapular and axillary views
Closed reduction maneuver	Sedation and relaxation of the patient is usually necessary (as bulky musculature in handball players may interfere with adequate relaxation and easy reduction), but not mandatory
Repeat neurovascular examination	Evaluate and document post-reduction neurovascular status
Immobilization in a sling/brace	

immobilization of the shoulder in slight external rotation better approximates the Bankart lesion to the glenoid than the conventional internal rotation position [58]; however, these results were not consistently reproduced, mainly due to malcompliance [59]. Overall, the rates of recurrent instability in the young, high-demand population approach 100% [60]. Also, the results of nonoperative treatment in young active adolescents with primary unidirectional dislocation have been poor, with estimative models predicting, i.e., the probability of redislocation in an 18-year-old male is 77% after 1 year and about 32% chance of having a stable shoulder in 10 years [61]. Handball players are a population at high risk based on this predictive model and the nature of the game, and therefore early surgical management in this population should be strongly considered, to reduce recurrence rates [62].

In primary glenohumeral dislocations in handball players, we recommend obtaining an early MR arthrogram. This enables a more accurate evaluation of the labrum and other lesions (i.e., PASTA lesions) and adds information relevant for decision-making. Alternatively, a CT arthrogram could be performed, adding valuable and very important additional information on the extent of bony deficiency, if applicable, as well as the condition of the labrum.

Fact Box

Traumatic shoulder dislocation is not common in Handball, however early surgical management should be strongly considered to reduce the risk of recurrence.

15.6 Microinstability and Subluxations

Although lacking a universally accepted definition, microinstability is broadly defined as any rotational or directional pathologic laxity that leads to abnormal mechanics without dislocation [4, 63]. The term **internal impingement** describes pathologic contact between the articular side of the rotator cuff and the posterosuperior margin of the glenoid [64] and was later linked to microinstability by others.

Kvitne and Jobe described the progressive attenuation of the static restraints of the shoulder, allowing anterior glenohumeral subluxation, with repetitive throwing when the repetitive stresses exceed that of tissue repair [65]. Initially, the dynamic stabilizers of the shoulder (rotator cuff, deltoid, biceps, and periscapular musculature) can compensate for mild instability with increased muscle activity; however, with prolonged activity and muscle fatigue, the humeral head may subluxate/translate anteriorly, allowing the rotator cuff to impinge along the posterosuperior border of the glenoid rim [65].

Jost et al. described findings correlating with microinstability and internal impingement in professional handball players, with typical findings in asymptomatic subjects including tendinopathies and partial rotator cuff tears, posterosuperior glenoid impingement, and impressive superolateral osteochondral defects of the humeral head [12].

Imaging findings on X-rays may reveal an ossification on the posteroinferior glenoid rim (Bennett lesion) and sclerotic changes of greater tuberosity, or rounding of the posterior glenoid rim may be seen [66]. MRI findings are usually subtle in the setting of microinstability and internal impingement and may include partial-thickness articular-sided rotator cuff tears of the supraspinatus and/or infraspinatus and posterior and/or superior labral tears. MRI findings associated with internal impingement include undersurface tearing of the supraspinatus or infraspinatus tendon, cystic changes in the posterior humeral head, and posterosuperior labral abnormalities [67].

A glenohumeral subluxation involves translation beyond the physiologic limits, while some amount of glenohumeral contact maintained and without the need for a manual reduction maneuver. Although this entity receives less attention, it has been documented that 85% of shoulder instability events in young athletes were subluxations, and only 15% were dislocations [68]. As handball is both a dynamic contact sport and an overhead throwing sport, many of these events may occur unnoticeably. Owens et al. documented first-time, traumatic, anterior subluxation events result in a high rate of labral and Hill-Sachs lesions in young athletes [69].

The mainstay of treatment in microinstability and internal impingement is conservative, and rehabilitation consists mainly of exercises focused on rotator cuff and scapular stabilizers strengthening (to improve dynamic stabilization of the shoulder) combined with posterior capsule stretching exercises. Of course, the specific rehabilitation protocol should be dictated by physical examination findings. For example, stretching of the posterior capsule and rotator cuff strengthening should be emphasized in patients with GIRD, as previously shown effective in high-level tennis players [4]. Indication for surgical treatment is not common and ranges from arthroscopic rotator cuff and labral debridement to capsular plication [70, 71]. Subluxation events are usually managed similar to frank instability events, depending on the level of symptoms and dysfunction.

15.7 The Unstable Painful Shoulder (UPS)

The unstable painful shoulder (UPS) is defined as anteroinferior instability of the shoulder without any apparent history of dislocations or subluxations, first defined by Patte et al. in 1980 [72] and later further developed by Boileau and colleagues [73]. The most important factor in diagnosing a UPS is to be aware of this uncommon diagnosis and to consider it as a possible cause in the young athlete. The diagnosis of UPS is often missed because the patients do not recall any episode of subluxation or dislocation, and, in addition, they do not feel that their shoulders are lax or unstable. Their only complaints are of chronic deep shoulder pain that prohibits overhead activities. They often report persistent symptoms that do not respond to rehabilitation and injections. The pain is not specific and the clinical examination is often confounding. This unusual presentation may account for the reported long delay between symptom onset and the final diagnosis (23–25 months) found by Boileau and colleagues [73]. The diagnosis of UPS should be suspected in a young (<30 years old) overhead athlete with deep shoulder pain that is resistant to conservative treatment. Interview of the patient should look for a direct or indirect forgotten trauma of the shoulder with the arm either at the side or in abduction and external rotation. The clinical suspicion that shoulder pain may be due to unrecognized instability should then be confirmed by physical examination and the discovery of rollover lesions with imaging or arthroscopy.

15.8 Posterior Instability

While traumatic posterior dislocations are very rear (although should not be missed!) in overhead throwers in general and handball players in particular, chronic posterior instability may be more common than previously perceived [74]. Posterior shoulder instability in the athlete is usually the result of repetitive microtrauma to the posterior shoulder complex, commonly occurring in handball. A spectrum of soft-tissue and bony pathologies may be encountered in posterior shoulder instability, the nature of which depends on the cause of the instability. Apart from various contact situations, both on offensive and defensive scenarios during matches, putting stress on the posterior structures, the nature of training in handball also exposes the players' shoulders to repetitive posteriorly directed microtrauma. Even standard weight room activities such as repetitive bench press lifting, overhead weight lifting, or any other activity which involves repetitive loading of the shoulder in front of the body can be sources of repetitive microtrauma [74]. In these activities, the shoulder is repetitively placed in a flexed and internally rotated position. The resulting posterior load causes lesions of the posterior labrum, frequently accompanied by stretching of the posteroinferior aspect of the capsule [75, 76].

Common soft-tissue findings may include a reverse Bankart lesion (tears of the posteroinferior aspect of the capsulolabral complex involving the posterior band of the inferior glenohumeral ligament) [30], posteroinferior capsular plastic deformation [75], "Kim lesion" (incomplete and concealed avulsion of the posteroinferior aspect of the labrum) [77], posterior labrocapsular periosteal sleeve avulsion (POLPSA) where the posterior labrum and the intact posterior scapular periosteum are stripped from the glenoid [78], "Bennett lesion" (an extra-articular curvilinear ossification along the posteroinferior glenoid near the attachment of the posterior band of the inferior glenohumeral ligament) [79], and posterior HAGL (posterior humeral avulsion of the glenohumeral ligament) representing an avulsion of the posterior band of the inferior glenohumeral ligament from its attachment on the humerus [80].

Common bony lesions include reverse bony Bankart lesion (more common following a traumatic event; less common in handball) and general posterior glenoid bone defects—mostly erosions as a result of repeated instability or subluxations [81]. There is a relationship between the extent of glenoid erosion seen on computed tomography and recurrent instability [81]. Another bony lesion is the reverse Hill-Sachs impression fracture (an osteochondral fracture of the anterior humeral head medial to the lesser tuberosity, in the region of the anatomic neck from impaction on the posterior glenoid rim), which may extend into the zone of contact between the humeral head and the glenoid during flexion, adduction, and internal rotation, producing subsequent engagement and subjective instability or dislocation [82].

15.9 Clinical Evaluation

When clinically evaluating the throwing shoulder in handball players and interpreting the various tests, it is important to distinguish between laxity and instability. Laxity is the asymptomatic passive translation of the humeral head on the glenoid and may even be important for athletic performance. In hyperlaxity, this range of joint motion and joint distractibility are increased without loss of function. Glenohumeral instability is defined as excessive translation of the humeral head on the glenoid associated with a functional deficit [47]. Laxity tests, therefore measure increased translation of the humeral head in different directions, such as the "sulcus test" (inferior) [33] and it's quantification [83] for anterior laxity, the Gagey test for inferior laxity [84] or the "Drawer test" (anteroposterior translation) [85].

Evaluation always starts with a thorough history taking followed by observation in a static position as well as dynamic observation of the shoulder in different positions. It is imperative to examine both the dominant and non-dominant shoulders for reference as well as to recognize physiologic laxity which may be present.

15.10 Stability Tests

Anterior apprehension test—The arm is abducted and externally rotated to 90° and then gradually further rotated. A positive test is defined when the patient becomes apprehensive—expresses fear of dislocating the shoulder (i.e., facial expressions, using contralateral arm to withhold the examiner, rotating the trunk in the direction to the examined shoulder). Pain is not interpreted as a positive test [86].

Relocation test—The patient is supine with the arm in the apprehension position (abduction and 90° of ER). The relocation test is considered positive when the patient's apprehensive complaints decrease with a posterior directed force on the humeral head or increase with an anterior directed force [87]. Pain alleviation with a posterior directed force is not considered a positive test.

The relocation test has also been described for the evaluation of internal impingement syndrome, however in this scenario, the test would elicit pain rather or more than apprehension, and the pain is relieved by the posterior force. This pain relief most probably results from the modification of the scapular orientation which unloads the contact between the cuff and the posterosuperior aspect of the glenoid. It is therefore very important to be attentive and cautious to distinguish between the symptoms generated through this manoeuvre in throwing shoulders. In our experience, the relocation test for anterior instability should be considered positive only if the predominant symptom elicited is apprehension and fear of shoulder dislocation.

Hyperabduction test—The examiner pushes the shoulder downward while lifting the arm passively in the maximally abducted position with the other hand, stressing the inferior glenohumeral ligament (IGHL) [84]. A positive hyperabduction test is defined as a side to side difference >10°. If there is a side to side difference associated with clinical symptoms, the hyperabduction test is considered an instability test. If there's increased hyperabduction in both shoulders and not associated with symptoms, it is considered a laxity test.

Jerk/posterior apprehension test [81]—While the patient is supine, the examiner brings the arm to 90° flexion, horizontal adduction, and internal rotation. An axial load is then placed in a posterior direction. The test is positive when the patient is apprehensive of dislocating the shoulder [88].

Assistance tests—Help detect muscular imbalance [89, 90]. **The scapular assistance test** is performed with the patient in the upright position. The examiner supports the back of the scapula, while the patient is asked to elevate the arm. The test is positive when either forward elevation is less painful with scapular support compared to without support, more comfortable, or if posterior subluxation is avoided. The **external rotation assistance test** is also performed with the patient in the upright position. The patient elevates the arm pressing externally on the examiner's hand. Resisted external rotation activates cuff muscles enhancing dynamic stability of glenohumeral joint. The test is positive when posterior shoulder dislocation is prevented during arm elevation with resisted external rotation.

15.11 Decision-Making and Management

Management of shoulder instability is multifactorial. Nonoperative management is the mainstay of treatment and allows return to sport in most cases, even at high playing levels, and at a much faster rate than operative treatment. This strategy may be useful for the in-season handball player looking to complete the season and then, if symptoms persist or worsen, undergo off-season stabilization. It may also be the most appropriate strategy in lower-demand players that do not wish to have surgery and without a traumatic cause. Surgical treatment is an option in patients that fail nonoperative management. Arthroscopic shoulder stabilization is a successful option, depending on the pathologic findings at the core of the instability problem. The most important factor in appropriate selection of surgical technique in handball players is an accurate evaluation of the amount of glenoid bone loss. This factor has been incorporated into the shoulder instability severity index score (ISIS), which was developed by Boileau to identify patients at risk for recurrence after arthroscopic Bankart repair [91]. The ISIS is a six-item, 10-point maximum questionnaire, which incorporates the importance of contact sports (with three points granted for participation in competitive contact or collision sports). In addition to sport participation, the other items on ISIS are age (less or greater than

20 years), presence of shoulder hyperlaxity, Hill-Sachs lesion on anterior-posterior radiographs, and glenoid loss of contour on anterior-posterior radiographs [91]. Patients with ISIS ≥6 have at least a 70% risk of recurrence with arthroscopic Bankart repair and therefore should undergo bony stabilization. Regardless of the approach (open vs arthroscopic), operative goals should be to fully define and anatomically address the pathologic lesion with secure fixation and appropriate ligament tensioning, establish healing potential and avoid complications. In contrast, arthroscopic Bankart repair has been sown to produce good outcomes with low recurrence rates in high-level contact or collision athletes without significant bone loss [92, 93].

Presence of significant glenoid bone loss (>20%) or inverted pear shape [94], with multiple recurrences, no Bankart lesion, poor-quality tissue, and abnormal capsular laxity are contraindications to arthroscopic labral repair [95].

Fact Box

Initial management of instability in handball players is conservative and most players do not require surgical intervention.

15.12 Arthroscopic and Bony Procedures

The most common procedures currently performed to address shoulder instability include arthroscopic Bankart repair and coracoid transfer (Latarjet-Bristow procedure) [96, 97].

Arthroscopic Bankart repair can be performed with the patient either in lateral decubitus or beach chair position. The technique basically relies on fixing the labral complex back to the glenoid by using suture anchors (Fig. 15.8a, b). Hyperlaxity or redundancy of the capsule can be simultaneously addressed by arthroscopic capsular shift both anteriorly and posteriorly if needed (Fig. 15.8c) [98].

However, capsular shift should be used with caution to avoid over-tensioning which could result in restrictions in ROM, particularly rotational deficits, therefore compromising throwing abilities. Recently, the remplissage technique has been shown beneficial, increasing effectiveness of soft-tissue arthroscopic techniques [99]. Dislocation rates have dropped in several studies down to 4% when glenoid bone loss was less than 20%. The remplissage technique relies on filling the Hill-Sachs lesion with the infraspinatus tendon by shifting and fixing the distal part of the tendon into the humeral defect using suture anchors. It is important to note that the remplissage technique has been shown to lead to a deficit in external rotation at short and midterm follow-up as well as potential residual pain posterosuperiorly [100, 101]. This may have limitations/implications for handball players as they require increased ER for their performance.

Larger deficits should be addressed by bone reconstruction procedures. The most common technique with the longest and largest evidence is the coracoid transfer (Latarjet-Bristow procedure) which has been mostly performed in an open fashion [102] (Fig. 15.9). Recently arthroscopic techniques have also been developed [103, 104] (Fig. 15.10). Regardless of the surgical approach, the coracoid tip with the attached conjoined tendon is resected and transferred through a split in the subscapularis tendon to be fixed onto the anterior glenoid. The technique restores osseous anatomy and provides a sling effect preventing dislocation in the abducted and externally rotated arm [102]. It is important to note that several authors have reported persisting residual pain subsequent to Coracoid transfer, which may have an impact on performance in elite handball athletes [105].

15.13 Management of Posterior Instability

The initial treatment approach for most posterior instability cases is nonoperative. Improvement or resolution of symptoms has been reported in up to 65–94% of the patients [106, 107]. Appropriate rehabilitation is particularly successful in atraumatic posterior instability, patients with diagnosed muscular imbalances (rotator cuff, scapular muscles, posture) and voluntary background.

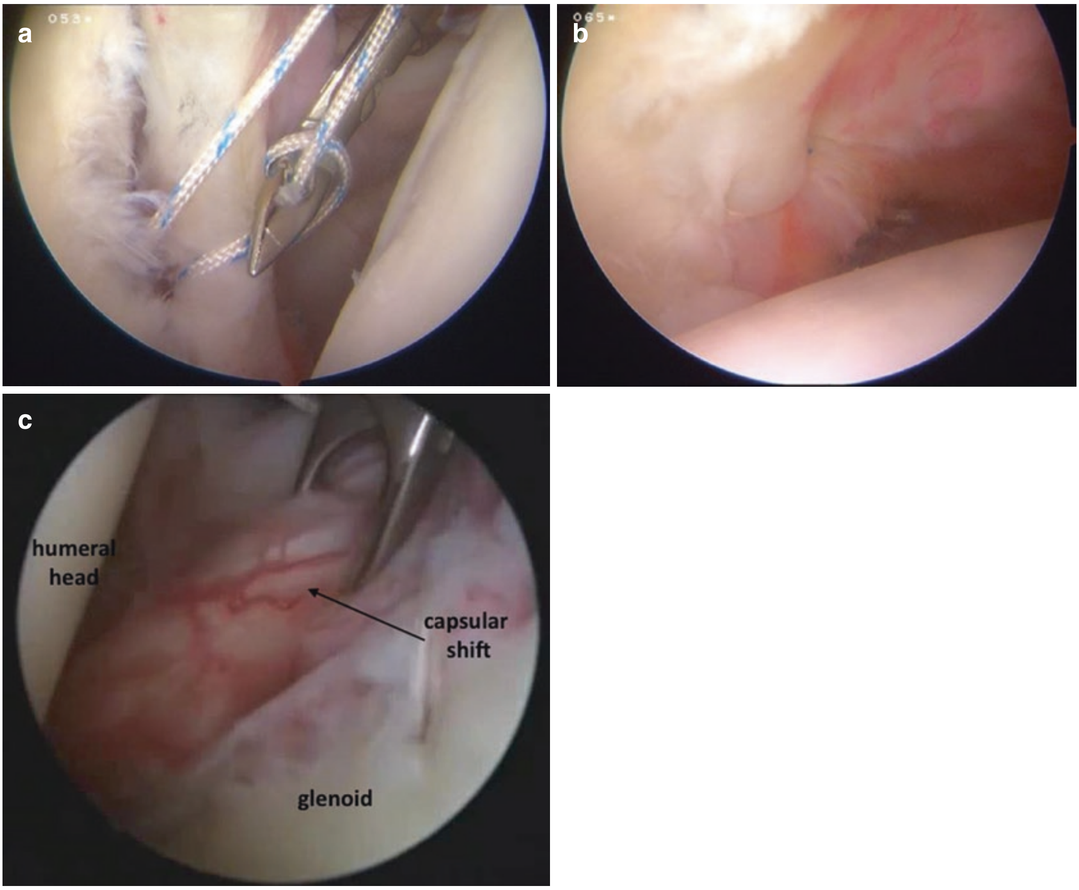

Fig. 15.8 Labral fixation with a suture anchor (**a**), reduced labrum after the fixation (**b**), Arthroscopic capsular shift (**c**) could sometimes be performed to address capsular hyperlaxity or redundancy

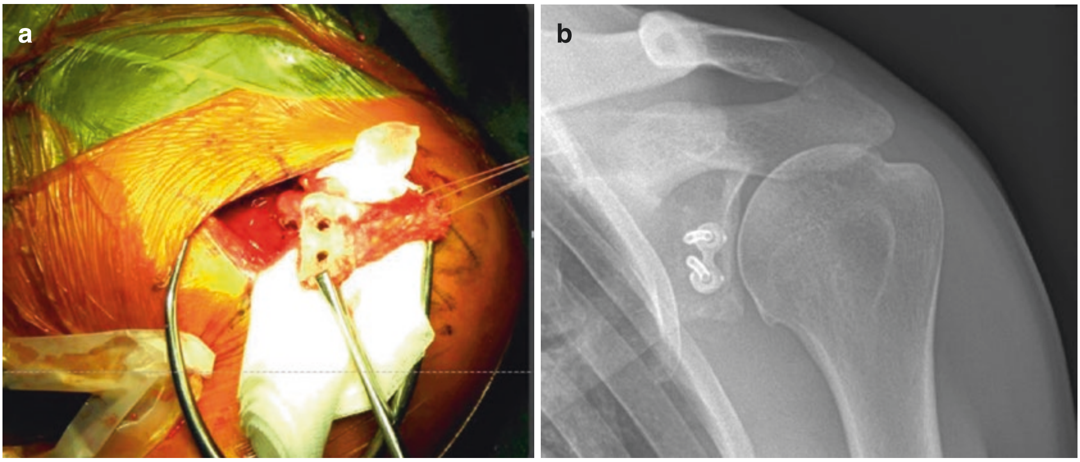

Fig. 15.9 Open coracoid transfer (Latarjet technique); the coracoid with the conjoined tendon are exposed after osteotomy (**a**), final radiographic picture with coracoid fixed with cannulated screws to anterior glenoid (**b**)

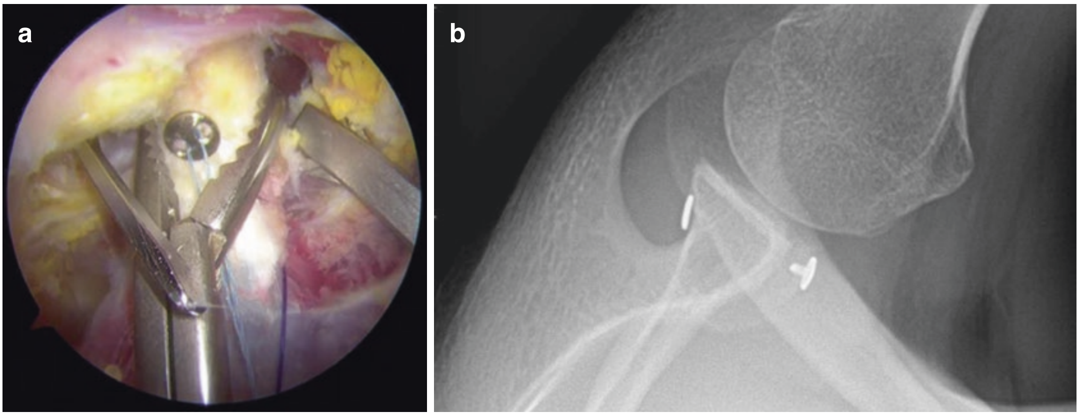

Fig. 15.10 Arthroscopic coracoid transfer with suspensory device fixation (Boileau technique). Coracoid tip with conjoined tendon transferred through subscapularis spilt into glenoid (**a**) and fixed with suspension device (**b**)

It has, however, been much less successful in cases of traumatic etiology and bone defects or increased glenoid retroversion or labral lesions [106, 108]. In such cases operative treatment provides better results [109, 110]. In our experience, most handball players presenting with posterior shoulder instability have a history of traumatic posterior subluxation or repetitive trauma. Clinical presentation of painful posterior shoulder instability (painful jerk test) is suggestive of tissue damage [77, 108]. Magnetic resonance arthrography (MRA) is therefore recommended to confirm diagnosis. Alternatively, a CT arthrogram could also provide extensive evaluation of both the osseous and soft-tissue structures. Depending on symptoms, athletes' performance level, and timing in the season, shoulder arthroscopy may be recommended early in the course of treatment in suitable cases. Surgical intervention may be also considered when recurrent posterior sub/dislocations occur despite a well-structured rehabilitation program [111]. Techniques should be adapted to the underlying pathology and may involve both open and arthroscopic approaches. The most common procedures for posterior instability are posterior labral fixation, capsular shift/plication, and bone block reconstruction (Fig. 15.11). Surgical treatment requires thorough postoperative regimen with partial immobilization initially, followed by a controlled rehabilitation process of 4–6 months before the athlete is cleared to return to play.

Fact Box
Surgical management should be based on the underlying pathology – mainly the existence and extent of bony deficiency.

15.14 Summary

The spectrum of shoulder instability in handball players is wide. Etiologies may range from distinct traumatic to repetitive microtrauma and overuse or a combination of these etiologies due to the nature of the sport, which is an overhead throwing contact sport. While instability may not be clearly evident in handball players and instability symptoms may not be distinct, it may be the underlying cause for throwing kinetic chain alterations and pathologic biomechanics leading to pain and decreased performance. It is therefore necessary to understand the spectrum of instability in handball players and obtain a detailed history, a thorough physical examination, and additional studies to arrive at a precise diagnosis. The treatment of shoulder instability in handball players should always start with a conservative approach focusing initially on restoring a painless full range of motion as a foundation for a smooth kinetic chain and addressing the specific deficiencies for each pathology. Most

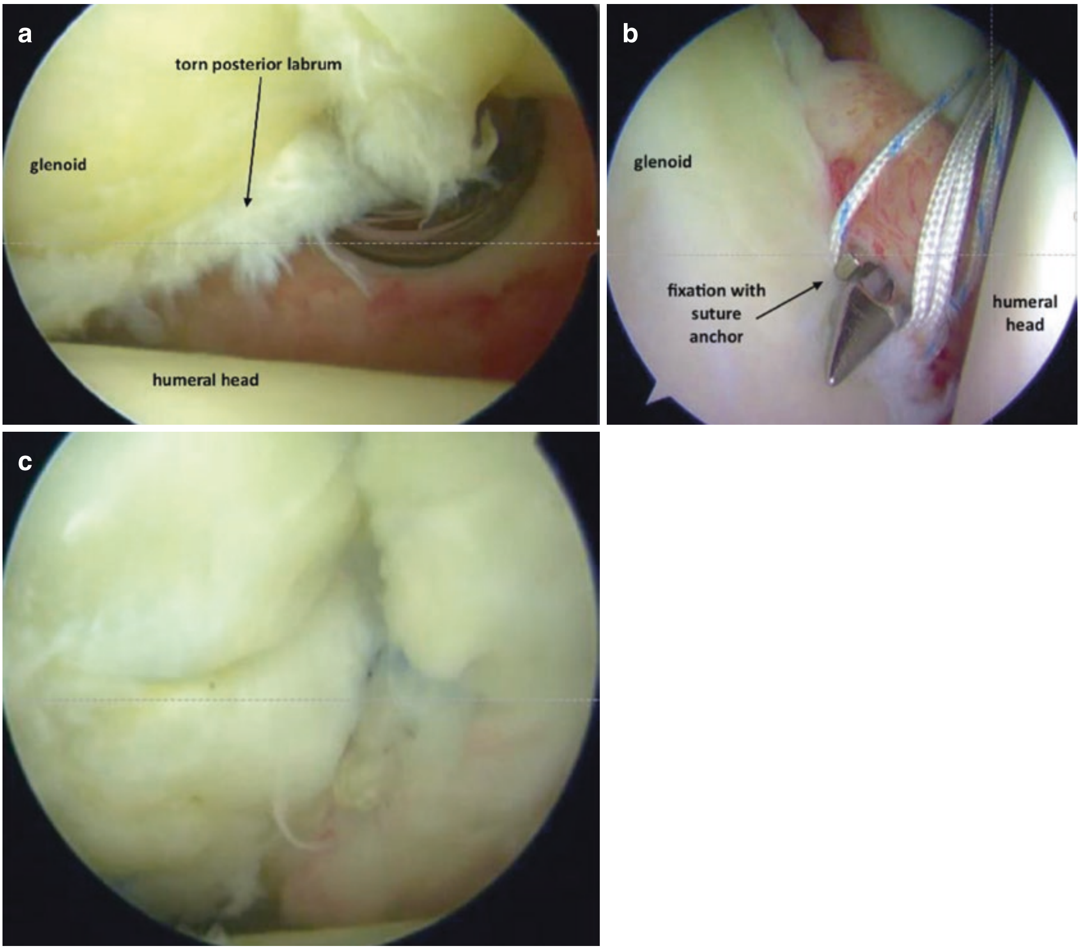

Fig. 15.11 Reverse Bankart tear (**a**), fixed with suture anchors (**b**) and reduced/stabilized after fixation (**c**)

instability cases in handball players can be managed conservatively, and only few will require surgical intervention. Surgical management is reserved for cases which failed to respond to appropriate conservative management and traumatic cases with major soft-tissue and bony deficiencies.

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Elbow Injury in Handball: Overuse Injuries

16

Nebojsa Popovic

16.1 Introduction

Handball is a popular team sport, and because of its popularity, handball injuries have recently become a subject of increased medical interest. Handball players impose high demands on their upper extremities, and a large number of elite handball players suffer from shoulder and elbow problems. Handball activities involving throwing, pushing, pulling and landing produce significant stress at the elbow joint that may result in wide variety of acute and chronic injuries. The elbow is an extremely difficult joint to manage following acute injuries due to the high degree of bony congruity, the close continuity of muscle to the capsule, the comminuted fracture patterns and unique response of the elbow capsule to trauma. The most common complication of acute elbow trauma is stiffness. An improved understanding of the aetiology and diagnosis of elbow fracture and instability has resulted from the attention given to this injury over the last decade, and, in turn, has led to better treatment and patient outcomes.

As 'throwing athletes', common overuse injuries of the elbow seen among handball players include medial tension injuries, lateral compression injuries, extension overload injuries and tendinopathies. 'Handball elbow [1]' is a popular term which has been used over the years to describe a variety of chronic pathologies occurring in and around the elbow. The author felt that despite this being a recognised problem among these athletes, it was important to define these terms accurately to eliminate confusion. It is also important to first secure an accurate diagnosis in order to make it possible to develop an effective treatment plan for these athletes, as well as subsequent preventive programmes.

16.2 Epidemiology

Two separate large epidemiological studies designed as a questionnaire survey concerning elbow problems in handball players [2, 3] have shown that the prevalence of past and present elbow problems was as high as 51% in goalkeepers and 32% in field players. The pain in these players was on the medial side of the elbow in 51% of cases. These findings suggest that the prevalence of elbow problems in handball is at least as high as that observed in tennis, golf and baseball. It may be argued that the reason for the high prevalence of elbow problems found in these studies [2, 3] is due to the broad definition of elbow injury used, which included any injury—even those which didn't cause missed playing time. This is contrary to other definitions

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of the injury commonly used in the literature [4, 5]. While it is likely impossible to compare cultural differences between sports, it is the experience of those working with handball players to note that they regularly continue to participate despite the presence of seemingly significant pathology. Injury definitions which only include missed games are likely to substantially underreport the true burden of this injury in handball players. In this regard, more modern approaches to injury reporting may prove useful [6].

It is important to mention that these studies [2, 3] identified two different patterns of elbow injuries in handball players:

1. Mechanism of repeated overhead throwing (73%) typically seen among field players (Fig. 16.1)
2. Repeated hyperextension trauma to the extended arm while blocking a ball, typically seen among goalkeepers (88.5%)

Fig. 16.1 Overhead throwing mechanism in field players

The majority of goalkeepers reported bilateral problems, whereas field players mainly complained of problems in their throwing arm.

16.3 Functional Anatomy

Understanding of the elbow anatomy is essential for the interpretation of elbow pathology. Knowledge of functional anatomy focusing on the relevant anatomic structures leads to a more meaningful interpretation of the overuse syndromes related to the elbow joint. The elbow joint comprises three functional systems: bone, ligaments and muscles. The bony articulation is a complex joint, composed of three articulations contained within a common joint cavity. The bony architecture provides approximately 55% of the stabilising contribution to the elbow, with static and dynamic stabilisers providing the remainder.

16.3.1 Static Stability

In addition to bony architecture, static stability of the elbow is provided by the anterior capsule and the medial and lateral collateral ligament complexes. The medial collateral ligament complex is composed of three components: the anterior band, the posterior band and the transverse band (Fig. 16.2). The anterior band is the strongest and most important portion of the MCL contributing 55–70% of valgus stability. The fan-shaped posterior band is a thickening of the capsule. It does not

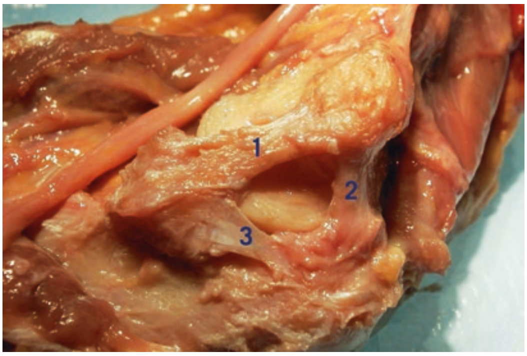

Fig. 16.2 Medial collateral ligament complex. (*1*) Anterior band, (*2*) posterior band, (*3*) transverse band

contribute significantly to valgus stability, except near-terminal flexion. The transverse band does not cross the elbow joint—its origin and insertion are both on the ulna—meaning it contributes little to stability. The lateral collateral ligament complex consists of four components: the annular ligament, the radial collateral ligament, the lateral ulnar collateral ligament and the accessory lateral collateral ligament. These ligaments provide varus stability to the elbow. This complex is therefore isometric throughout the normal range of flexion and extension of the elbow joint. Controversy about function of the different components of the lateral collateral ligament still exists in the literature.

16.3.2 Dynamic Stability

Four muscle groups control elbow joint stability: flexors and extensors of the elbow and pronators and supinators of the proximal radio-ulnar joint. Dynamic stability of the elbow joint is in part related to the flexor and extensor muscles providing compression across the joint, increasing the inherent stability provided by the highly congruent articular surface. Further stability may be gained because of a bulk effect: the brachialis and triceps muscles in particular have broad cross-sectional areas, and their insertions are close to the axis of joint rotation. The alignment of the muscles that cross the medial side of the elbow joint favours dynamic protection of the medial collateral ligament complex (Fig. 16.3). On the medial side of the elbow, the flexor carpi ulnaris (FCU) is the most important dynamic stabiliser, with the flexor digitorum superficialis playing a less significant role. The role of the anconeus muscle remains unclear, but its location suggests that it may be an important dynamic constraint to varus and posterolateral rotatory instability.

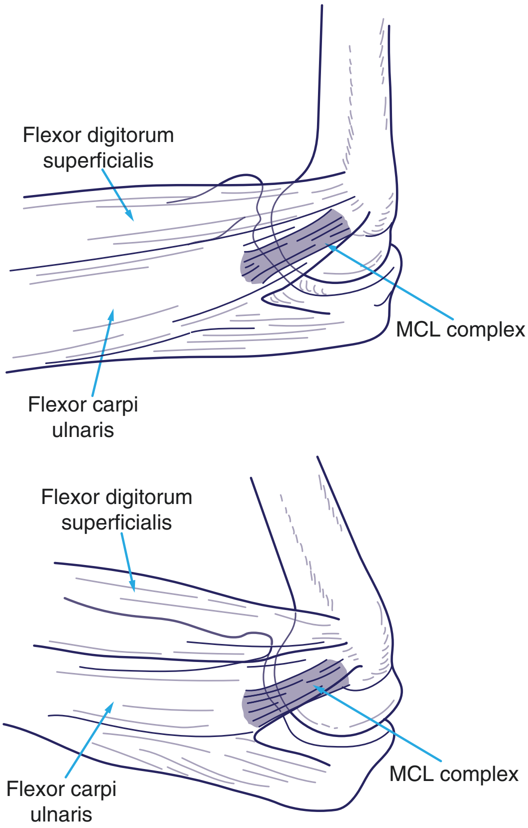

Fig. 16.3 Dynamic protection of the MCL complex

16.4 Elbow Problems in Field Players

For field players, the main injury mechanism of elbow overuse problems is repetitive throwing. During overhead throwing, players place repetitive high valgus stress on the medial aspect of the elbow joint. During a normal season of handball practice and competition, each field player performs around 60,000 throwing motions at a speed up to 130 km/h [1].

Throwing is a highly dynamic activity in which body segments move through large arcs of motion with high movement speeds, and, subsequently, large joint forces and torques are generated at the elbow. During each throw in handball, the elbow is subject to both imposed forces and functional demands, and it is best disposed to control movement in the sagittal (flexion/extension) plane. However, during throwing, large rotational torques are generated at the shoulder and transmitted to the elbow as valgus stress which the passive and active restraints are ill-equipped to deal with. This presents a major challenge to the stabilising structures. In the throwing arm, an enormous amount of force is generated about the medial aspect of the elbow during late cocking and early acceleration phase of throwing. This

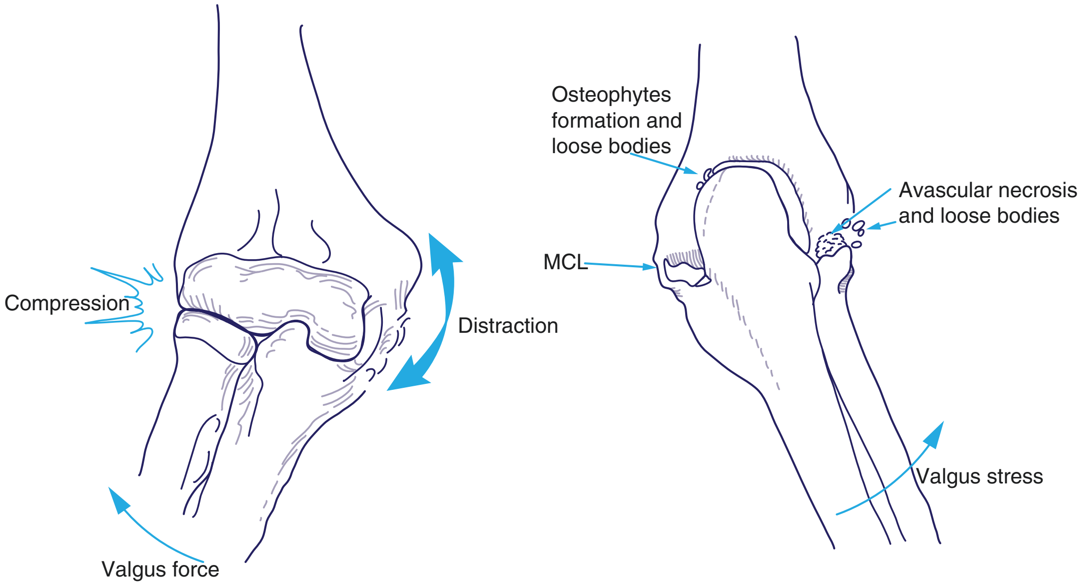

Fig. 16.4 Valgus extension overload injury to the elbow in throwing athletes

force is transmitted to the medial collateral ligament complex, radiocapitellar articulation and the surrounding soft tissue structures.

Slocum [1] was the first to describe valgus extension overload injuries to the elbow in throwing athletes as the triad of medial tension, lateral compression and posterior impingement injuries (Fig. 16.4). Most of these elbow injuries involve soft tissue, including ligaments, tendon, muscle and cartilage.

16.4.1 Medial Compartment

Medial tension stress is responsible for most localised injuries of the elbow observed in field handball players. Medial musculotendinous injuries are quite common in these players, especially those involving the muscles that originate at medial epicondyle flexor-pronator mass. These muscles act to dynamically assist in controlling elbow stability while throwing. Because of the intensity of activity, number of repetitions and abnormal forces occurring from valgus stress, the MCL is at high risk of injury. Over time these abnormal forces can lead to microscopic tearing of the soft tissue of the MCL with imperfect healing. This chronic attenuation of the MCL with repeated high valgus stress can lead to dynamic medial instability. The medial collateral ligament is most susceptible to injury when the flexor-pronator muscle mass weakens and fatigues due to repetitive throwing and overuse. Subtle injury of this ligament can lead to dynamic medial instability of the elbow in these athletes.

16.4.2 Lateral Compartment

The lateral compartment of the elbow in field handball players is subject to high compressive forces which can lead to lateral elbow compression injury. According to Morrey et al. [7], 33% of the varus torque needed to resist valgus torque applied by the forearm is supplied by the joint articulation. This valgus torque can cause compression between the radial head and the humeral capitellum. Inappropriate muscle contraction, especially about the elbow, or loss of joint integrity on the medial side of the elbow can cause this compressive force to increase. This excessive or repetitive compressive force can result in avascular necrosis, osteochondritis dissecans or osteochondral chip fractures in the lateral compartment.

In elite handball players, this repetitive valgus stress in the presence of an incompetent MCL results in a radiocapitellar overload syndrome. This chronic radiocapitellar overload produces degenerative changes in the articular cartilage. Consequently loose-body formation can occur as articular cartilage fragments break off into the joint. In these cases athletes report pain associated with catching, clicking or locking of the elbow.

16.4.3 Posterior Compartment of the Elbow

Valgus extension overload syndrome is a common final pathway for posterior elbow problems that result from excessive valgus forces. After repetitive extension of the elbow during throwing, the olecranon is repeatedly and forcefully driven into the olecranon fossa. This can result in posteromedial olecranon impingement within the olecranon fossa, especially in athletes with an attenuated medial collateral ligament. The tip of the olecranon, which is intra-articular, causes local inflammation and, if this persists, eventually chondromalacia and osteophyte formation. With continued impingement, these osteophytes can break off and become loose bodies within the joint. Loose bodies may cause a mechanical block to flexion or extension or may produce synovitis resulting in an effusion and a stiff elbow. Bony hypertrophy of the olecranon and narrowing of the olecranon fossa have been reported in throwing athletes, predisposing these athletes to impingement of the olecranon process on the medial wall of the olecranon fossa. These athletes have pain with full extension, passive or active, which can lead to limitation of elbow extension range.

16.5 Acute-on-Chronic Medial Elbow Mechanism

This type of injury mechanism is unique to field players in handball and rarely seen in other throwing sports due handball being a contact throwing sport. Chronic overuse of the elbow in in field players due to repetitive throwing can weaken the native structural elements of the medial elbow, and having a shot suddenly and violently blocked by a defending player can lead to a significant acute lesion of the medial collateral ligament (Figs. 16.5 and 16.6).


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Fig. 16.5 One particular high-risk mechanism of medial collateral ligament tear in the elbow is when a defending player blocks a shot while the attacker's elbow is in maximum valgus extension overload

Fig. 16.6 A frequent mechanism of medial collateral ligament tear in the elbow is when a defending player blocks an attacker's shot from behind, while the attacking player's elbow is in maximum valgus overload

16.6 Imaging of Overuse Injuries in Field Players

Careful imaging of the elbow joint focusing on the relevant anatomic structures leads to more meaningful interpretation and prevents the physician from missing coexisting pathologies.

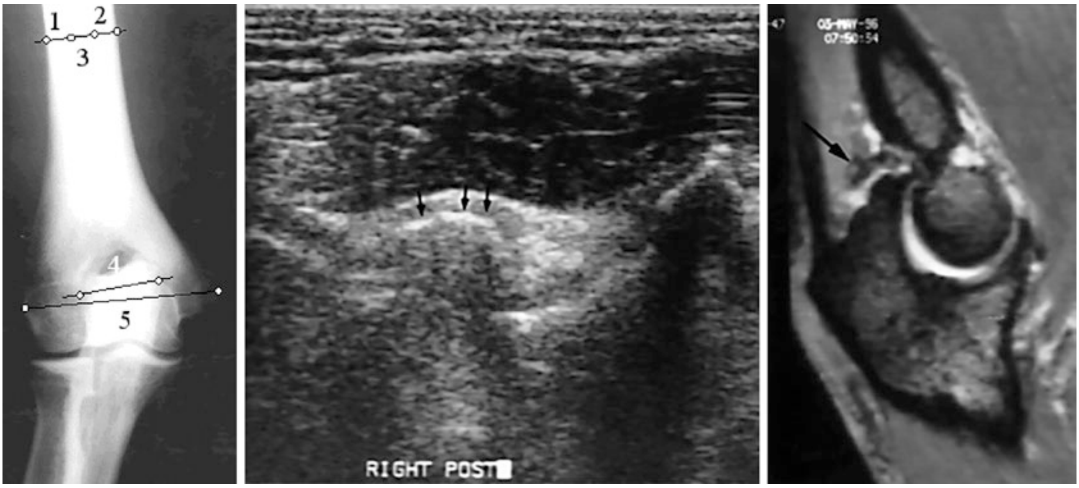

Fig. 16.7 Imaging manifestation (X-ray, ultrasound, MRI) of elbow overuse in handball players

Radiographic evaluation is helpful in evaluating the elbow joint for overuse injury. Plain radiographs which include anteroposterior, lateral, oblique and axial views can identify degenerative changes and loose bodies in the elbow. The posteromedial osteophyte is seen easily on the anteroposterior view and the hyperflexion axial view.

Valgus stress radiography has been described by some authors as an important tool in diagnosing elbow instability [3, 8]. If stress radiography is used, comparison should be made with the contralateral elbow as valgus stress radiography used only on the injured elbow can lead to a false-positive laxity findings.

Ultrasound is an excellent modality for rapid comparative evaluation of soft tissue pathology around the elbow. It is an inexpensive technique and well-tolerated by the patient. It is, however, limited in its ability to demonstrate the entire articular cartilage and is operator-dependent.

MRI provides clinically useful information in assessing the elbow joint and has become the method of choice in evaluating elbow problems in throwing athletes. Integrity of the ligaments and associated injuries are readily seen as well as articular surfaces and adjacent neuromuscular structures. Administered gadolinium may provide additional information in an assessment of throwing elbow pathology.

The imaging manifestations of musculoskeletal stress at the elbow associated with handball have been studied by Popovic et al. [3] (Fig. 16.7). In their study using comparative plain films, stress radiographs, ultrasound and MRI in 40 uninjured elite handball field players, the authors tried to compare the manifestations of elbow stress due to repetitive valgus forces between the dominant and non-dominant elbow in these athletes. Generalised bony hypertrophy of the dominant extremity on X-ray was observed in all players. A significantly greater medial joint opening was measured in the dominant elbow compared with the non-dominant elbow. The ultrasound findings showed statistically significant bilateral differences in thickness of the flexor-pronator tendon, extensor tendon, MCL and triceps tendon, and values were systematically higher in the dominant elbow. In 33% of the players, small loose bodies were found in the dominant elbow. MRI confirmed these findings, which suggests that US alone can be useful in describing these features clinically. This study confirmed that repetitive stress on the dominant elbow in field handball players is responsible for physiologic and pathologic changes.

16.7 Elbow Injury in Goalkeepers

Injury of the elbow caused by direct force to the forearm, pushing the elbow in hyperextension, may be acute, in which case the athlete is usually unable to continue activity, or chronic, when the athlete feels sudden pain but is able to continue playing.

The first description of hyperextension injury in handball goalkeepers was published in 1986 by Popovic [1]. Impact injuries of the elbow in handball goalkeepers caused by the ball hitting a fully extended distal part of the forearm have been further well-described by Tyrdal et al. [9]. According to their epidemiological study, 75% of goalkeepers in team handball experience elbow problems during their career. Almost all (95%) goalkeepers sustained their injuries through hyperextension trauma of the elbow when blocking shots. The ball impact on the forearm of a goalkeeper is considerable at a speed that can reach between 100 and 130 km/h with the ball weighing 475 g (Fig. 16.8).

As we know from previous studies, the medial collateral ligament complex of the elbow is the predominant stabiliser to valgus stress [7, 10]. The relationship between the functional tightness of the different bands of the anterior oblique complex of the MCL and the degree of elbow flexion may help to explain elbow lesions in handball goalkeepers depending on the position of the elbow at the time of injury. When blocking the shot, the elbow is in extension away from the body. This position of the upper extremity tightens the anterior bundles of the anterior oblique complex. The force of the blow to the forearm produces a valgus load on the elbow and stresses the anterior bundles of the medial collateral ligament complex.

In the cadaveric study designed to mimic injury mechanism seen in handball goalkeepers, Tyrdal et al. [9] confirmed that the anatomic lesions produced on the specimens were consistent with injury mechanism in handball goalkeepers. His study confirms some patterns of elbow lesion such as L-shaped ruptures of the pronator-flexor origin with elongation of the anterior part of the medial collateral ligament, anterior capsule rupture and occasional incomplete rupture of the lateral collateral ligament and localised fragmentation of the cartilage near the posterior edge of the ulna (Fig. 16.9). The majority of lesions produced by the mechanism of traumatic hyperextension were the lesions of the medial side of the elbow. While these injuries begin with an acute trauma, the symptoms soon become chronic as the athlete continues to suffer intermittent aggravations while continuing to play despite the medial elbow pain.

Fig. 16.8 Impact injury by elbow hyperextension mechanism in handball goalkeepers

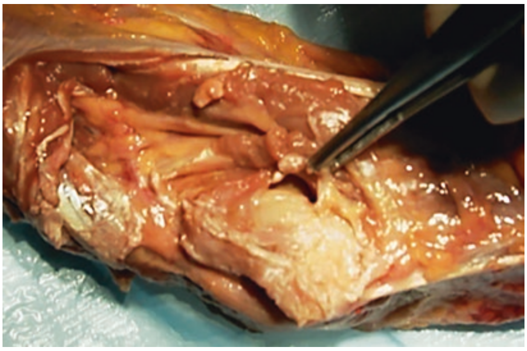

Fig. 16.9 Cadaveric study showing an L-shaped rupture of the pronator-flexor origin

In a study on imaging of the elbow lesions caused by hyperextension in 30 handball goalkeepers [11], authors found important pathological changes on X-ray, US and MRI. No significant differences were found between the dominant and non-dominant elbow in these mostly asymptomatic athletes. The radiological findings in that study demonstrated hypertrophic osteophytes and traction spurs in 67%, loose bodies in 5.5% and periarticular calcification in 5.5% of cases.

Stress radiographs using a Telos stress device with 15 daN valgus stress confirm medial joint opening in some players that probably reflects certain MCL laxity in goalkeepers as a consequence of repetitive hyperextension trauma of the elbow joint.

Ultrasonographic examination in this study disclosed joint effusion in 67% of the goalkeepers elbow, mainly (44%) in the annular recess as well as the coronoid fossa (39%) and the olecranon fossa (33%).

Thickening of the MCL flexor-pronator tendon and triceps tendon of both elbows in goalkeepers compared with the normal population was demonstrated on US examination. We can argue that repetitive hyperextension trauma of the elbow in these athletes results in micro rupture of the soft tissue around the elbow with imperfect healing process of the MCL, flexor-pronator tendon, extensor tendon and triceps tendon resulting in thickening of these structures seen on US examination.

Based on the findings in this imaging study [11], it seems that repetitive hyperextension stress of the elbow in handball goalkeepers provokes small amounts of various pathologic changes confirmed on US examination and increased medial laxity of the elbow as seen on stress radiography. This laxity can ultimately lead to chronic repetitive injuries of the elbow especially, in goalkeepers with poor dynamic muscular stabilisation of the elbow. However, athletes who participate in other sports that involve similar impact injuries of the elbow, such as soccer goalkeepers and volleyball players, can be likewise affected.

16.8 Treatment

The treatment of elbow overuse injuries in handball players is always conservative, with rest and appropriate physiotherapy, and progressive return to throwing activities. Indications for medial collateral ligament reconstruction are very rare in these athletes and should only be considered in players who are unable to return to play after appropriate conservative treatment.

16.9 Prevention of Elbow Overuses Injuries in Handball

Through proper conditioning, training and surveillance, some overuse injuries of the elbow in handball players can be avoided. It is important to consider the key issues for elbow overuse injuries in handball; in field players, the number of throwing repetitions is the most important factor, but in goalkeepers it is exposure to repeated hyperextension trauma to the forearm while blocking shots. Overuse or overload elbow injuries in handball players are always more common at the beginning of the season or during periods of increased load due to major competition. When athletes return to play handball after significant period of rest (e.g. when returning from the off-season) or elbow overuse injuries, their return should be slow and progressive. Elbow injury prevention programmes for handball players should consider all of the discussed risk factors and mechanisms of elbow overuse injuries.

16.10 Conclusion

The published literature [1–3, 5, 9, 11] clearly demonstrates a high prevalence of elbow overuse problems among handball players, with two different typical injury patterns and similar imaging findings. Therefore, we would suggest that the term ‘handball elbow’ should be accepted in the sports medicine literature.

16.11 Take-Home Message

The elbow joint in handball players is subject to great valgus stress and, as a result, is exposed to a wide variety of possible injuries. Epidemiological studies show that medial elbow pain affects a significant number of players in handball, with prevalence at least as high as observed in other throwing sports. The most common mechanism of injury is repetitive throwing motion in field players and repetitive hyperextension trauma to the extended arm in goalkeepers.

Biomechanical analysis of the throwing motion in field players revealed that transition from the late cocking phase to early acceleration phase places extreme valgus stress on the medial structures of the elbow. These repeated insults are largely to blame for the patterns of elbow injury seen.

Pathomechanics of hyperextension trauma similar to that of handball goalkeepers, as shown in cadaveric studies, can cause four types of lesions [9]:

1. Anterior capsule rupture
2. Transversal and longitudinal rupture of the flexor-pronator origin with elongation of the anterior part of the MCL
3. Occasionally incomplete rupture of LCL
4. Detachment of small fragments of cartilage near the posterior edge of the olecranon

Based on imaging studies [3, 11] it is reasonable to conclude that repetitive valgus stress in field players results in typical overuse injuries of the dominant elbow. On the other hand, repetitive hyperextension stress of the elbow in handball goalkeepers provokes similar pathologic changes bilaterally.

On the basis of these findings, the existence of two different specific elbow injury patterns can be confirmed in handball players. In the long term, they provoke similar final overuse injuries of the elbow, which can be designated with a general term such as ‘handball elbow’.

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17

Wrist and Hand Injuries in Handball

Lionel Pesquer and Grégoire Chick

17.1 Introduction

Handball is practiced at different levels: recreational, competitive (amateur), or professional. A high-level athlete usually competes at a national or international level. This contact sport is a frequent source of wrist and hand injuries, which are often underestimated or neglected. Besides the challenge of the sport itself, there are economic stakes and obligations to the media for professional players who have a unique psychological profile: their risk of injury is greater because of more frequent high-energy traumas in highly trained individuals without hand protection.

The thumb and the pinkie play a major role in catching the ball which fits perfectly in the palm of the hand: the thumb stabilizes the ball and the pinkie locks it into position. During a jump shot, the shoulder is pulled back, the elbow is in semi-flexion, and the wrist is flexed at the end of the movement with the fingers pointed toward the target. Full range of motion is required in the wrist to perform certain movements such as the **spin shot** or the “roucoulette” (Fig. 17.1).

The hand and wrist are often injured by direct impact during a block, from direct contact with another player especially during one-to-one situations from pulling a shirt or during a fall. The goalkeeper can injure his/her wrist during forced dorsiflexion when catching a ball thrown at more than 140 km/h.

Injuries may involve one or more structures:

- Bone: scaphoid or triquetrum fracture
- Ligaments: scapholunate ligament, triangular fibrocartilage complex ligament (TFCC), and ulnar collateral ligament of the metacarpophalangeal joint of the thumb
- Joints: capsuloligamentous structures and the volar plate of the metacarpophalangeal and interphalangeal joints
- Tendons: flexor and extensor tendon tears of the fingers

Diagnosis imaging is a valuable part of the comprehensive physical examination of the injured hand, but care must be taken when interpreting results because chronic or previous coexisting lesions are often present. Standard X-rays and US are the primary imaging modalities to be performed; CT scans or MRI with or without enhancement should be discussed depending on the suspected injuries.

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Fig. 17.1 (**a**, **b**) The thumb and the pinkie play a major role in catching the ball which fits perfectly in the palm of the hand: the thumb stabilizes the ball and the pinkie locks it into position. (**c**) During a jump shot, the shoulder is pulled back, the elbow is in semi-flexion, and the wrist is flexed at the end of the movement with the fingers pointed toward the target. (**d**) The hand and wrist are often injured by direct impact during a block

The goal of treatment is to enable the quickest return to play in the best conditions without jeopardizing the athlete's professional future or his career change. The main question is when and how to treat? Several elements must be taken into account and include the player's position, age, dominant hand, the beginning or end of the season, the beginning or end of the playing career, and specific regulations for splinting challenging follow-up (travel, treatment compliance). A consensus opinion should be obtained for the therapeutic strategy with sports doctors, hand specialists, radiologists, and hand therapists. The hand surgeon must gain the athlete's trust. Prevention must not be forgotten because of the risk of new injuries or potential post-traumatic osteoarthritis in fragile limbs.

The goal of this chapter is to describe three types of injuries in handball players.

- Scaphoid fracture
- Thumb sprain
- Sprains and dislocations of the PIP joints

17.2 Epidemiology

Handball is one of the Olympic sports with the highest risk of injuries [1]. There are a clear predominance of traumatic injuries in previous reports and a high prevalence of overuse injuries as well. Center backs and goalkeepers have the highest risk of distal injuries to the upper extremity [2]. During the world championship in Qatar in 2015, the upper limbs were involved in 16.7% of cases: including the wrist 1.5%, hand 0.8%, fingers 3.8%, and thumb 1.5% [2]. Injuries from one-to-one situations accounted for 61.4% of the cases. A study following elite Brazilian National league players during a full season in 2011 reported finger injuries in 9%, thumb injuries in 6%, and wrist injuries in 3% of the players. Table 17.1 describes the frequency of hand, wrist, and finger injuries from various studies [3].

Table 17.1 Frequency (% of total) of hand, wrist, and finger injuries by location, gender, and study

Study	Frequency
Fagerli et al. [4]	37% (female)
Jorgensen [5]	6% (male)
Seil et al. [6]	11% (male)
Langevoort et al. [7]	9% (female) 7% (male)
Olsen et al. [8]	18% (male and female combined)
Nielsen and Yde [9]	Senior: 20% (male) Junior: 23% (female); 7% (male)
Wedderkop et al. [10]	1% (female)
Moller et al. [11] (male and female combined)	Senior: Traumatic, 9.4%; overuse, 3.5% U-18: Traumatic, 14.6%; overuse, 4.7% U-16: Traumatic, 12.3%; overuse, none
Giroto et al. [3]	13.4% (male and female combined) 15.3% (female); 11% (male)

Fact Box
Handball is a contact sport
Injuries to the fingers are often neglected
The conditions and delay to return to play determine the treatment strategy.

17.3 Scaphoid Fractures

Scaphoid fractures are the most frequent fractures of the carpal bones (60–90%) [12–14]. Early recognition is important, because delayed treatment or failure to diagnose may lead to complications [15, 16].

17.3.1 Anatomy of the Scaphoid

The scaphoid is divided into three parts: the body (zones III, IV and V), the proximal pole (zones I and II), and the distal pole (zone VI). The tubercle is found between zones IV and V (Fig. 17.2). Eighty percent of the surface of the scaphoid is covered by cartilage. Vascularization is poor and originates from the dorsal branch of the radial artery. Vascularization of the proximal pole is retrograde, which creates a risk of necrosis [17] or nonunion [15] in the presence of a proximal fracture.

17.3.2 Mechanism of Injury

Most common mechanism of scaphoid fracture is a wrist hyperextension with radial deviation and internal rotation, after a fall on the outstretched hand [18]. Sometimes the fracture occurs from receiving a high velocity ball in the hand forcing the wrist back (goalkeeper) or when blocking a shot.

17.3.3 Physical Examination

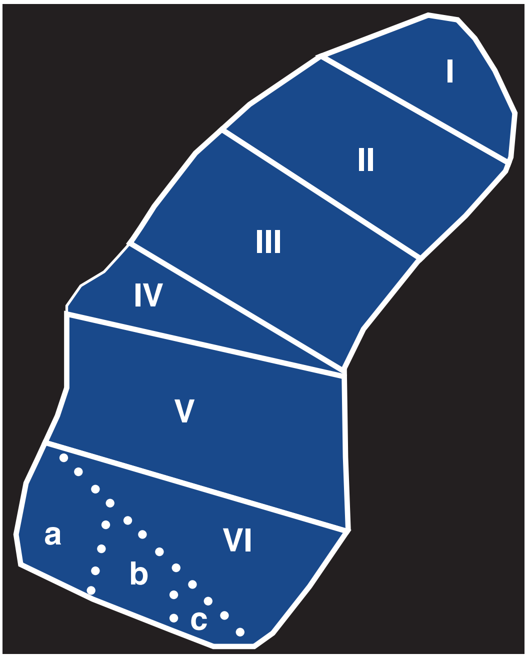


Fig. 17.2 Schematic drawing of Shernberg classification

The physical examination usually shows swelling of the anatomical snuffbox, sometimes with bruising. Pain may be present and can be provoked by placing direct pressure on the snuffbox during traction or axial compression of the column of the thumb. The clinical examination has a positive predictive value of approximately 21%. If there is no pain in the anatomical snuffbox, a scaphoid fracture can be nearly completely excluded [14].

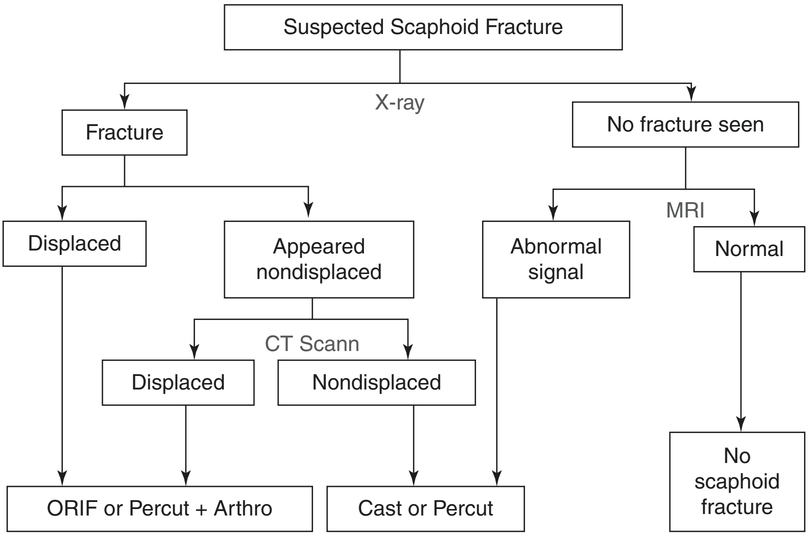
17.3.4 Imaging

On X-rays the percentage of misdiagnosed fractures varies between 7 and 50% depending upon the study, with a mean 20% [14]. If there is no visible fracture, more sensitive complementary imaging should be performed (Table 17.2).

17.3.4.1 MRI Vs. CT Scan

MR imaging is the most sensitive and specific imaging modality for the detection of scaphoid fractures [19] in particular trabecular fractures [20]. T1-weighted sequences provide the best visualization of the fracture, while a bone marrow edema is easier to assess on T2-weighted or STIR sequences [14]. Two percent of bony contusions progress to fracture: in these cases, rest with immobilization is recommended followed

Table 17.2 Algorythme: diagnostic and therapeutic options in case of suspected scaphoid fracture



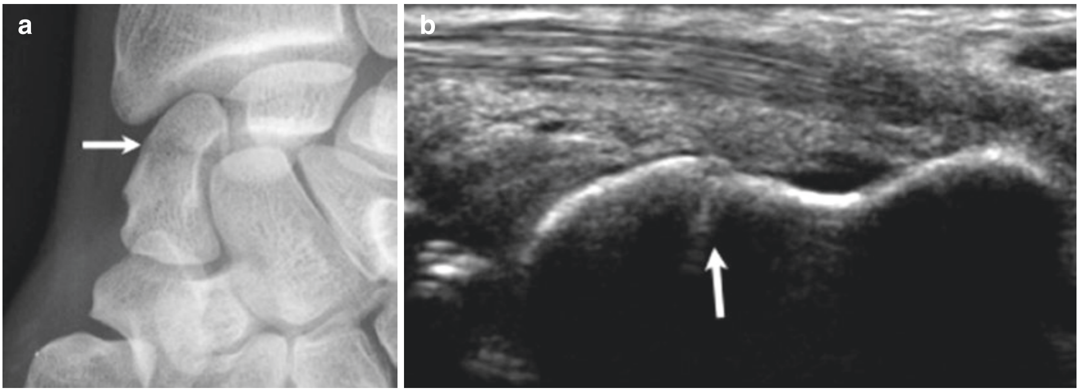


Fig. 17.3 A 24-year-old male player with wrist pain following direct trauma. X-rays (**a**) and ultrasound with oblique longitudinal view in the scaphoid long axis (**b**) show proximal pole fracture of the scaphoid

by a CT scan after 6 weeks [21]. **CT scan** allows a better assessment of bone, improving visualization of cortical fractures and displacement, and identifies 30% of occult fractures that were not initially visible on X-rays [22].

17.3.4.2 US

Ultrasound is highly accessible and provides detection of occult fractures with a sensitivity of between 50 and 100% and a specificity of between 65 and 100% [23–26]. Cortical disruption is the most important diagnostic criterion [24], and hemarthrosis or a subperiosteal hematoma may be identified in the soft tissue. Ultrasound can also be used to evaluate the ligaments with excellent results for the scapholunate ligament (Fig. 17.3).

17.3.5 Classification and Distribution of Scaphoid Fractures

The Herbert and Fischer [27, 28] classification is most frequently used; parameters include the appearance of the fracture, whether it is stable (type A) or not (type B) and whether it is chronic (Type C). Fractures of the scaphoid waist are more frequent (65–70%) than proximal pole fractures (15%) [18]. Approximately 70% of fractures are unstable [10]. A fracture is called displaced when there is more than 1 mm of displacement, angular displacement of more than 10° or in case of comminuted fractures (Fig. 17.4).

17.3.6 Treatment

The treatment strategy is based on imaging results. The risk of nonunion in displaced fractures treated with a cast is four times greater than in non-displaced fractures treated in the same manner [29]. Whatever the treatment strategy, a physical examination and CT scan should be performed every 6 weeks until union is ended up.

17.3.6.1 Conservative Treatment

A thumb spica cast below the elbow is applied. The thumb does not need to be immobilized if CT scan or MRI confirms the presence of a non-displaced fracture of the scaphoid waist [30]. The hand is immobilized for 9 to 12 weeks, and union is ended up in nearly 90% of cases [31]. Return to sport is possible with a playing cast after 3 months when it is allowed (Fig. 17.5). A physical rehabilitation program is needed to prevent stiffness and loss of muscle tone.

17.3.6.2 Surgical Treatment

Depending on the fracture site, fracture reduction then stabilization is obtained with proximo-distal (distal approach) or disto-proximal (volar

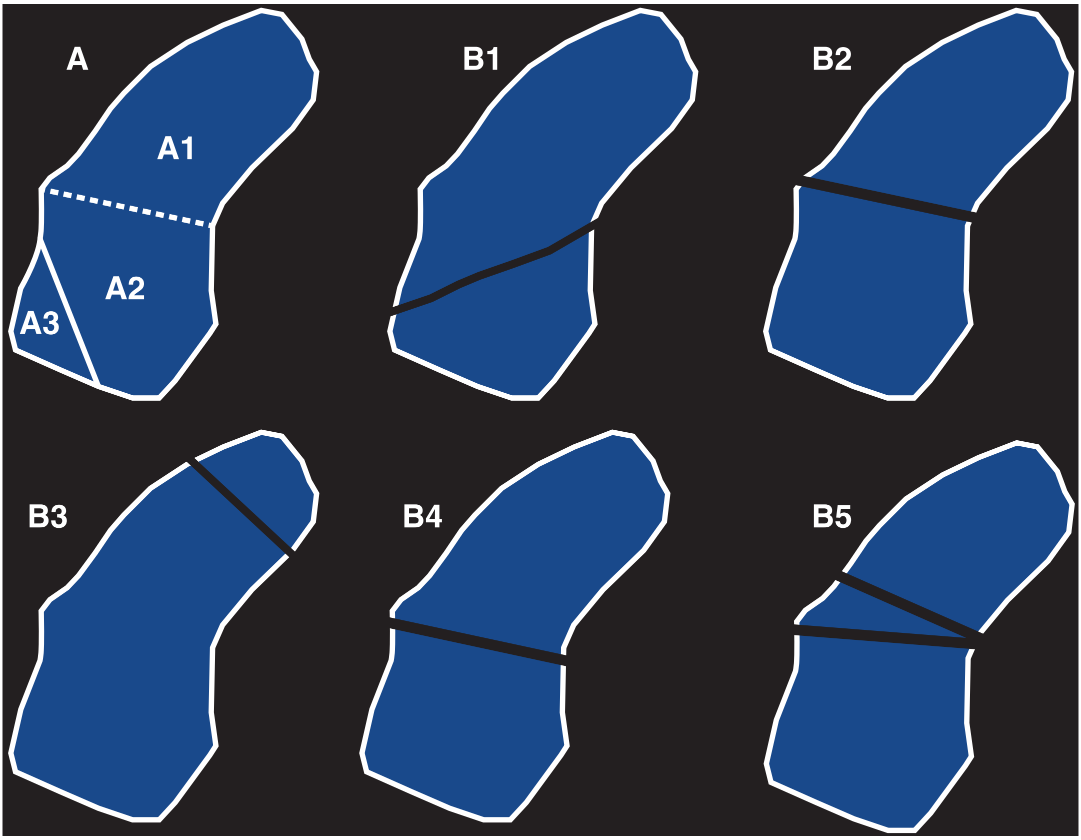


Fig. 17.4 Herbert classification

Fig. 17.5 Playing cast

approach) compression screw fixation, percutaneously (non-displaced fracture) or by open surgery (displaced fracture). Percutaneous screw fixation prevents devascularization during surgery and reduces morbidity [32].

Postoperative immobilization is not necessary or lasts less than 3 weeks [33]. However, complications such as screw malposition or too long screw, scapho-trapezial impingement, or an extensor tendon injury are frequent, up to 23% [30]. Authors have reported that screw removal is required in 16% of patients [34–37]. Forced or against resistance movements are possible when healing is ended up [31–33] at a mean of 7 weeks after surgery [33, 38]. Return to sport is possible after the 8th week, as long as there is full range of motion, no pain, and satisfactory strength and if 50% of bridging bone is seen on CT scan [39]. Splinting protection should continue for 1 month more, and then the athlete can return to play without protection after 3 months.

17.3.6.3 Indications

Conservative treatment is limited to stable and non-displaced fractures (type A). Surgery is indicated in displaced fractures. This choice of treatment has important consequences for an active athlete and his/her surgeon: the duration of immobilization (3 months) and its consequences (stiffness, loss of strength, loss of muscle tone) means that the season is ended for the player. Percutaneous screw fixation allows immediate movement of the wrist, results in faster time to union and return to sport with good function [40–42]. This treatment option is advised in athletes, especially high-level players. The risks of surgery should be explained and accepted by the player.

17.3.7 Complications

17.3.7.1 Nonunion

Nonunion corresponds to a fracture that does not heal after 6 months, while before this period was considered to be delayed union. If fractures are diagnosed rapidly and treated correctly, union is obtained in 8–12 weeks in 90% of cases [43], depending upon the type of fracture, its location, and whether the fracture is displaced or not. Time to union is also influenced by whether the fracture line is distal, horizontal, or perpendicular to the central axis of the scaphoid and by the extent of displacement. Nonunion progresses to osteoarthritis in 100% of cases [44]: shortening of the palmar cortical length increases the intra-scaphoid angle resulting in a *humpback deformity* when the lunate slips into fixed extension to cause DISI (*dorsal intercalated segment instability*) deformation. Progressive osteoarthritis develops, affecting the styloid process of the radius and capito-scaphoid and lunato-capitate joints (SNAC, *scaphoid nonunion advanced collapse*).

17.3.7.2 Malunion

This corresponds to displaced fractures that heal in an abnormal position, with the scaphoid in flexion, causing adaptive carpal modifications and secondary osteoarthritis (SNAC wrist).

17.3.7.3 Osteonecrosis

The incidence of osteonecrosis in fractures of the middle third of the scaphoid is 30% and nearly 100% in more proximal fractures [18]. MRI is a useful diagnostic tool to differentiate early necrosis from progressive ischemia requiring a bone graft. Gadolinium intravenous injection confirms necrosis in the absence of clear enhancement [44].

Fact Box

Early diagnosis and appropriate treatment provide the best chances of union.

Nonunion always results in osteoarthritis.

Recovery of wrist function is faster with percutaneous screw fixation in nondisplaced fractures of the scaphoid waist.

17.4 Thumb Sprain

Injury to the metacarpophalangeal (MCP) joint of the thumb is frequent with a severity ranging from a benign sprain to fracture-dislocation. The ulnar collateral ligament (UCL) is much more frequently injured than the radial collateral ligament (RCL) and is involved in 50% of thumb sprains. Chronic instability may develop without treatment. The main problem in athletes is to decide when to treat because thumb stability must be restored for good functional recovery.

17.4.1 Mechanism of Injury

During a fall, an acute stress places the structures of the ulnar ligaments under tension. The intensity of abduction can cause an associated lesion of the dorsal capsule and/or the volar plate or even MCP dislocation. In handball, holding the ball increases hyperabduction and the stress on the thumb during a fall. The UCL is also at risk of injury during a block or when catching the ball. Repeated injuries (“gamekeeper’s thumb”) or an untreated tear can result in chronic UCL instability [45].

17.4.2 Anatomy

Stability of the MCP joint of the thumb is necessary for pollicidigital grasps. Joint congruence is not important because it is a condyloid joint. The static stabilizing structures are the ulnar and radial collateral ligaments, the volar plate, and the dorsal joint capsule (Fig. 17.6a). The dynamic stabilizers are extensor pollicis brevis and longus, flexor pollicis longus, adductor pollicis, and flexor pollicis brevis. The adductor pollicis muscle of the thumb covers 75% of the distal insertion of the UCL. Its aponeurosis inserts into the ulnar side of the base of the proximal phalanx of the thumb. Normally, during movements of the distal phalanx, the aponeurotic expansion of the adductor slides easily over the surface of the ulnar collateral ligament. During a simple sprain in abduction and extension, there is pulling or partial tearing of one or several bundles of the proper and accessory UCL. In a severe sprain with a Stener lesion, the adductor aponeurosis of the thumb is interposed between the torn end of the UCL and its attachment on the proximal phalanx [46]. Repetitive injuries or untreated tears can cause chronic instability (Fig. 17.7).

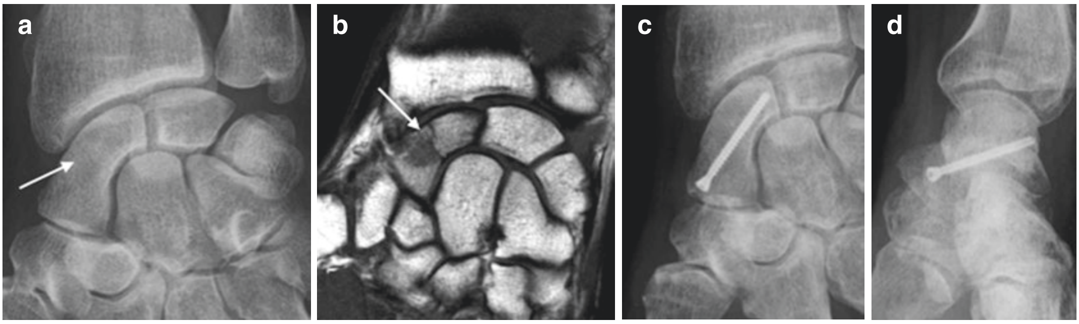


Fig. 17.6 A 27-year-old female player with scaphoid fracture at zone III. X-rays (**a**) and MRI with T1-weighted sequence in the coronal plane (**b**) before surgery. X-rays with anteroposterior (**c**) and lateral (**d**) after percutaneous screw fixation

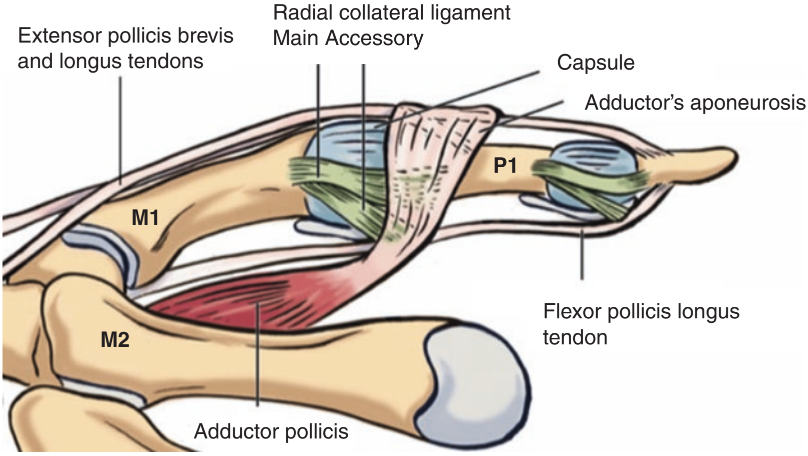


Fig. 17.7 Schematic drawing of the medial aspect of the MCP of the thumb

17.4.3 Clinical Examination

There is diffuse swelling of the MCP joint which is tender at physical examination. A test of lateral stability should only be performed after a radiograph has confirmed there is no associated fracture. In case of bony avulsion of the distal end of the ligament, the ligament should not be tested because there is a risk of displacing the fragment if it is near the proximal phalanx. A valgus stress test is performed with the joint in 20 to 30° of flexion (proper ligament) and extension (accessory ligament) (Fig. 17.8). If it is too painful, the maneuver should be performed under local anesthesia. Stress testing should be bilateral and comparative (particularly in the presence of constitutional laxity): if laxity is a greater than 30° or 15° more than the opposite side, a UCL tear is confirmed [47]. If there is laxity in extension, injury to the accessory collateral ligament is suggested and may be associated with a palmar plate injury.

Fig. 17.8 Clinical examination of the MCP joint with valgus stress

17.4.4 Imaging

True AP and lateral X-rays of the MCP joint can identify any displacement in relation to the proximal phalanx, the orientation of any avulsion fractures (Fig. 17.9), and the subluxation or lateral deviation of the proximal phalanx. Volar MCP joint subluxation may be identified, suggesting injury to the accessory stabilizers, usually the dorsal capsule [45].

US is the best tool to investigate an MCP sprain with a sensitivity and specificity of 92 [48] to 100% [49]. Bone surfaces and ligament structures can be directly visualized, and dynamic US can identify any interposition or impingement. US is performed with the hand flat, the thumb slightly abducted, and the probe parallel to the first ray on the medial side of the MCP joint. A normal ligament appears as a linear fibrillar structure that is stretched from one edge of the joint to the other under the adductor aponeurosis expansion. In severe sprains there is a complete tear with an echogenic ovoid mass on the proximal side of the joint (Fig. 17.10). Two dynamic tests can be performed:

- A valgus stress test of the MCP joint of the thumb to place the UCL under tension
- A flexion-extension stress test of the interphalangeal joint of the thumb to study sliding of the expansion of the adductor aponeurosis on the surface of the UCL and identify any interposition and the presence of a Stener lesion

Fig. 17.9 A 22-year-old player with proximal phalanx fracture

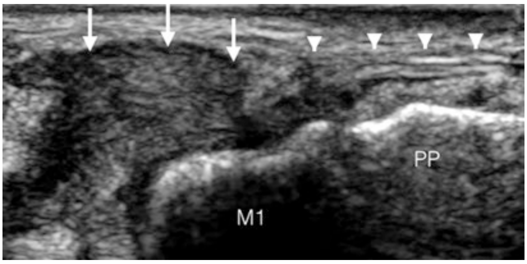


Fig. 17.10 A 25-year-old player with Stener lesion. Ultrasound shows a complete tear of the ulnar collateral ligament with an echogenic ovoid mass (*white arrows*) and the interposed adductor aponeurosis (*arrowheads*)

17.5 MRI

The sensitivity and specificity of MRI is similar to that of US [50, 51]. Axial and coronal T2-weighted sequences show a nodular area of low intensity on the proximal side of the joint with a “cauliflower” appearance, corresponding to the end of the proximal ligament that is retracted and raised by interposition of the expansion of the adductor aponeurosis (Fig. 17.11). Although visualization of the position of the ligament in relation to the aponeurosis is good, the lack of dynamic testing limits the accuracy of this examination [52, 53].

17.5.1 Classification

Following the clinical examination, an MCP sprain can be classified into three grades [54]:

- Grade 1: simple sprain. Tenderness without laxity of the collateral ligament

Fig. 17.11 A 24-year-old player with Stener lesion. MRI with coronal T2-weighted with fat saturation sequence shows a complete tear of ulnar collateral ligament (black arrowhead) and the interposed adductor aponeurosis (white arrowhead)

– Grade 2: partial ligament tear with laxity but with a firm end point
– Grade 3: complete tear with significant laxity, with or without a Stener lesion

17.5.2 Treatment

UCL sprains without instability may be treated conservatively. The thumb is immobilized in a rigid splint that covers the base and leaves the interphalangeal joint free. The first web should be open, and the MCP joint slightly flexed to allow opposition of the pulp of the thumb with the neighboring fingers. Two splints may be used: a functional alpine splint is lighter than a thumb spica cast (Fig. 17.12), but immobilization is less stable. This is recommended for grade 1 or 2 sprains. Grade 1 sprains are immobilized for 3 weeks, and flexion and extension mobilization is then begun. Varus and valgus grasping is allowed after 6 weeks to prevent any tension of the collateral ligaments.

Surgical treatment of patients with complete ligament tears confirmed on imaging but without clinical laxity is a subject of debate. Most authors recommend conservative treatment [55], while others prefer surgery. Conservative treatment includes immobilization for 4 weeks followed by a protective splint at night or during high-risk activities for 2 weeks. Physical rehabilitation is begun after 4 weeks. In case of a non-displaced avulsion fracture, conservative treatment is used similar that of a grade 2 sprain.

Surgery is indicated in the following cases [56]:

– Interposition of the aponeurosis of the adductor of the thumb (Stener lesion)
– Presence of a displaced avulsion fracture
– Interposition of the dorsal capsule or the volar plate

The goal of treatment is to obtain anatomical repair of the injured ligament. Avulsion fractures of the UCL usually occur at the base of the proximal phalanx and are less frequent in the ligament itself and at the metacarpal head. The proper ligament is repositioned with a suture anchor or a pullout-type trans-osseous suture [57]. In case of a bony fragment that is more than 20% of the joint surface, a screw or K-wire device is used for fixation. If the lesion is into the ligament, a direct suture is performed.

Immobilization is similar to that of a grade 2 injury: 4 weeks of strict immobilization then 2 weeks at night and during high-risk activities. Physical rehabilitation is begun after the fourth week with flexion and extension mobilization. Activities that place stress on the MCP joint are not allowed without protection until after week 12.

17.5.3 Complications

All patients with an MCP sprain should be informed that the pain when shaking hands and grasping objects will gradually decrease in 6–8 months. Swelling may persist. Pain is often associated with stiffness during flexion that should be prevented by early mobilization. In case of inadequate treatment, the main risk is instability, which can effect pollicidigital grasping, as well as weakness. Then, over time, post-traumatic MCP osteoarthritis may develop. Identification of the radial nerve is essential during surgical ligament repair: injury to this nerve is one of the most frequent complication in these cases.

Fig. 17.12 Conservative treatment. (**a**) Alpine splint. (**b**) Thumb spica cast. (**c**) Taping

17.5.4 Timing and Return to Sports

Return to sport in ball players depends upon whether the athlete can wear a rigid protective splint and can grasp the ball if it is the dominant hand, the player's position.

The notion of a chronic sprain is difficult to define, but it may be considered chronic when direct ligament repair is not possible, usually after 6–8 weeks. In that case, the date of surgery can be adapted to the athlete's playing season:

- Off-season: the goal is to return to play the next season.
- During and at the beginning of the season: surgical treatment.
- At the end of the season: taping.
- In the middle of the season: it depends upon the amount of time left before the season ends and the quality of the ligament on MR imaging.

The delay before the return to handball is between 6 and 12 weeks, with protective taping for 3 months [58].

Fact Box

A bilateral clinical examination is important to determine instability and should be preceded by X-rays.

Surgical treatment is mandatory in complete or unstable injuries.

Conservative treatment is performed for partial and stable injuries.

An adequate treatment is essential to prevent chronic instability.

17.6 Sprain and Dislocation of the Long Fingers

In handball, the proximal interphalangeal (PIP) joint and the pinkie are often injured. If misdiagnosed, instability may develop as well as stiffness, boutonnière deformity, and osteoarthritis. Injuries range from a simple sprain (jammed finger) to a complex fracture-dislocation (Fig. 17.13). These injuries are often overlooked and should not be neglected.

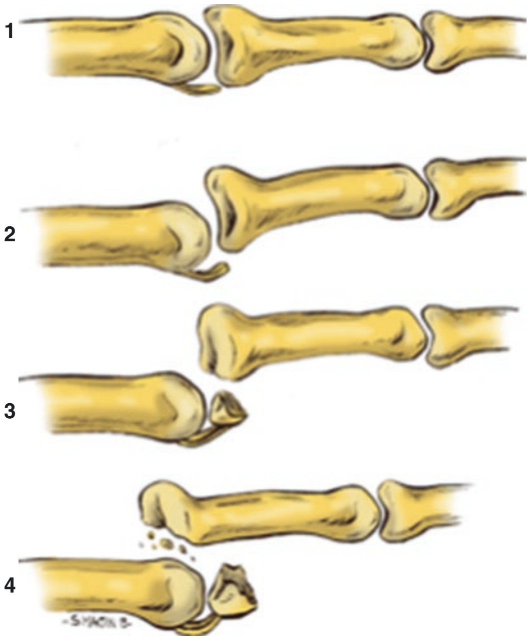


Fig. 17.13 Proximal interphalangeal sprains. *1*: Normal. *2*: Tear of the volar plate. *3*: Tear of the volar plate with bony avulsion. *4*: Fracture-dislocation

17.6.1 Mechanism

Unlike the MCP joints, the collateral ligaments of the PIP and distal interphalangeal joint (DIP) are tense during extension and relaxed during flexion. Most injuries are benign sprains following a direct ± axial impact from a ball or physical contact during play. Depending upon the direction and force of the impact, one or several of the following structures may be more or less severely injured: collateral ligaments, volar plate, and central slip of the extensor mechanism. At least two of these structures must be fully torn for dislocation to occur. Ninety percent of dislocations are dorsal and reduced immediately on the playing field.

17.6.2 Physical Examination

Pain and local swelling is common (Fig. 17.14). When testing the joint in extension, there is clear lateral instability in the case of a complete ligament tear. Even with a partial tear, swelling may persist for several months and be associated with reduced and painful flexion [59].

17.6.3 Imaging

AP and lateral X-rays are performed to search for a volar plate avulsion fracture (Fig. 17.14), a lateral avulsion at the base of the proximal phalanx, dislocation, or subluxation. CT scan can be useful in case of a fracture-dislocation. US and MRI are the reference diagnostic tools to assess ligament and tendon structures as well as the volar plate [60].

17.6.4 Clinical Forms

- Benign sprain: ligament injury with or without an avulsion fracture.

US is useful to differentiate a pulled ligament from a partial or complete tear. The outcome is usually good, but improvement is often slow with persistent pain, stiffness, and swelling for several months.

- Severe sprain: volar plate injury.

It is usually distal and lateral and progresses rapidly to retraction in the presence of a complete rupture. It is associated with an avulsion fracture at the base of the middle phalanx in 30–40% of cases. On US or MRI, the volar plate may not be identifiable near the joint space and may be displaced to the metacarpal neck. Recovery is usually long with swelling and chronic stiffness. There may also be rapid progression to a swan neck deformity in case of a distal tear or a “pseudo-boutonnière” deformity in case of a proximal tear. Instability is rare.

- Differential diagnosis: tear of the central slip of the extensor mechanism.

This is a classic diagnostic challenge because there is no tendon retraction and extension is preserved initially due to the absence of lateral band injury. This may progress to a boutonnière deformity associating flexion of the PIP and extension of the DIP [61]. Identification by US may be difficult because the central slip is thin; comparison of adjacent digits is essential to search for a significant hypoechoic edema. Stress testing in flexion is essential to differentiate a partial tear from a complete tear. In case of complete rupture there is no movement of the slip proximal to the PIP during flexion and extension. Surgical treatment is difficult in chronic or advanced forms [60].

Fig. 17.14 A 33-year-old player with PIP sprain. Swelling of the PIP joint with bony avulsion at X-rays

17.6.5 Treatment

Treatment of sprains is nearly always conservative [59]. The goal is to recover finger motion as rapidly as possible. The potential of spontaneous healing is high because the collateral ligaments will spontaneously return to their correct position, even after dislocation. The main risk is stiffness, particularly during flexion, because the volar plate tends to retract. It is therefore especially important to immobilize the PIP in full extension. Immobilization is short, between 7 and 10 days, and may be continued at night for 3 weeks.

Dorsal dislocations are easier to reduce on the playing field than volar dislocations which are less frequent, especially in the presence of malrotation of the middle phalanx (interposition). After reduction, stress testing of the central slip of the extensor should be performed because surgical repair is necessary if it is completely torn.

Surgery is indicated in non-reducible dislocations with interposition of the volar plate, in the presence of significant instability following reduction with a temporary k-wire for stabilization and when the central slip is torn in volar dislocations.

17.6.6 Complications

Extension stiffness may occur due to retraction of the volar plate following incorrect immobilization and prolonged flexion or chronic instability from repeated injuries. Secondary osteoarthritis is rare.

17.6.7 Therapeutic Features in Handball Players

The diagnosis and the type of injury are determined by the cause of injury and the physical examination: in case of dorsal PIP dislocation, the finger is immediately reduced on the field by the medical team before swelling and pain develops. The main problem is identifying the severity of the injury. If the athlete can immediately return to play with buddy taping of the injured finger with the neighboring finger, a rapid evaluation is necessary by a specialist to test joint stability. In case of a stable and reduced PIP dislocation, protection by buddy taping is necessary for 2–4 weeks, and the player may return to play without protection after between 4 weeks and 3 months. In case of instability after reduction, extension block splinting must be performed, full extension of the finger is possible after 4–6 weeks, and the patient may return to play 3 weeks later with buddy taping. In severe injuries, such as unsuccessful reduction, instability following reduction, or suspected associated fractures or tendon injuries, the player should be evacuated for correct treatment by a specialist. Preventive treatment by taping is useful in ball sports (defense) depending on the level and frequency of play (Fig. 17.15).

Fact Box

Very frequent sprains (particularly the PIP joint) that are benign with appropriate initial treatment.
Stability of the collateral ligaments to be tested in flexion for the MP and in extension for the PIP.
Conservative treatment in most cases.
The goal is motion for the long fingers.
Some types of injuries that may require surgery must be identified by a specialist.

Fig. 17.15 Conservative treatment with taping

17.7 Take-Home Message

"Timing, Not Only When to Perform Surgery But Also When to Clear An Athlete For Return To Play After Treatment, Is Complex And Multifactorial."

MG Carlson Elite athlete's hand and wrist injury. Hand clinics 2012.

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18 Hip, Groin, and Abdominal Injuries in Handball

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18.1 Introduction

Hip and groin injuries in handball have received less attention compared to other sports such as the football codes and ice hockey. However, a few reports exist on the incidence of hip and groin injuries in handball based on data from major elite tournaments, full handball seasons, and cohorts of athletes diagnosed with hip and groin pain. Hip and groin injury data derived from major elite tournaments, such as the Olympics and the World Championship, report a consistent incidence of 1.5–4%, with a higher incidence in men's handball (3–4%) compared to women's handball (1.5–2%) [1, 2]. A recent study from the Men's Handball World Championship in 2015 distinguishing between groin and hip injuries reported four groin injuries and a single hip injury constituting 3% and 0.8% percent of all injuries reported during the tournament, respectively [3]. As only fit and healthy players are typically included in a squad competing in major tournaments, such data on hip and groin injuries may not reflect the proportion of these injuries during a full handball season.

When deriving injury data from full season studies, hip and groin injury rates seem to be higher compared to major tournaments. In elite senior handball hip and groin injuries constitute up to 12.5% and 11% of all overuse and acute injuries, respectively [4]. However, considerably lower incidence have also been reported in elite senior handball, with hip and groin injuries constituting 0.9% and 7.6% of all acute injuries, respectively, and 1.3% and 0% of all overuse injuries, respectively [5]. Compared to elite handball, the proportion of hip and groin injuries seem to be lower in non-elite [6] and young handball players [4, 7] constituting 5.5% and 2–10% of all injuries, respectively.

The large variation in the proportion of hip and groin injuries observed in the above studies may likely be explained by the varying injury definitions, grouping of injuries, reporting of injuries,

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level of sport, and age. However, nonetheless the data indicate that hip and groin injuries are prevalent in elite, non-elite, and youth handball.

In diagnostic cohort studies investigating the distribution of clinical groin entities in athletes with hip and groin pain, handball players represent up to 5% of athletes diagnosed with long-standing groin pain, primarily categorized as adductor- and iliopsoas-related groin pain [8, 9]. Furthermore, in a prospective cohort study investigating acute groin injuries handball players represented 11% and 3% of athletes with an acute hip adductor or proximal hip flexor injury, respectively [10, 11]. To the authors' knowledge, no such detailed data exist on hip injuries in handball players specifically. However, our experience suggests that intra-articular hip pathology, such as femoroacetabular impingement syndrome (FAIS), is a prevalent issue among handball players.

	Proportion of hip and/or groin injuries
Major elite tournaments	1.5–4%
Full handball season	0.9–12.5%
Diagnostic cohort studies	3–11%[a]

[a]Proportion of handball players diagnosed with hip and/or groin injuries in relation to all athletes included in the studies

18.2 Risk Factors

A systematic review [12] including 29 studies found level 1 and 2 evidence that a number of factors are associated with an increased risk of groin injury in athletes. The most commonly found factor was previous groin injury (Level1), while higher level of play (Level 1), decreased hip adduction strength (both relative to abduction and by itself) (Level 2), and lower levels of sport-specific training were also recognized (Level 2).

Another systematic review examined cross-sectional factors differentiating athletes with and without hip and groin pain [13]. They found 17 cross-sectional studies of which 10 were high quality. In total 62 different measures were investigated. Eight studies were suitable for meta-analysis. A meta-analysis of eight of these studies showed pain and lower strength on adductor squeeze test, and reduced hip internal rotation and bent knee fall out were frequent findings in athletes with hip and groin pain.

18.3 Diagnosis, Entities, and Terminology

Terminology, definitions and classification of hip and groin pain in athletes have been a major problem with lack of consensus. Unspecific and confusing terms like athletic pubalgia, core muscle injury, pubic aponeurosis injury, and osteitis pubis have been used both clinically and in the literature [14]. In 2015 the Doha agreement paper was published in an attempt to change that [15]. A large group of experts from all over the world including general and orthopedic surgeons, physiotherapists, sports physicians, and radiologists agreed to adopt the concept of uniformly recognized entities and defined a number of such entities, based on a clinical classification system, which covered the most common causes of groin pain. Table 18.1 presents the entities as they were defined in the agreement. The primary focus was on the classical groin injuries and included adductor-related, iliopsoas-related, inguinal-related, and pubic-related groin pain [15]. The

Table 18.1 Clinical entities as defined at the Doha agreement meeting 2014

Clinical entities	Clinical symptoms and signs
Adductor-related groin pain	Adductor tenderness and pain on resisted adduction testing
Iliopsoas-related groin pain	Iliopsoas tenderness plus, more likely if pain on resisted hip flexion and/or pain on hip flexor stretching
Inguinal-related groin pain	Pain located in the inguinal canal region and tenderness of the inguinal canal. No palpable inguinal hernia is present. More likely if aggravated by abdominal resistance or valsalva/cough/sneeze
Pubic-related groin pain	Local tenderness of the pubic symphysis and the immediately adjacent bone. No particular resistance tests to test specifically for pubic-related groin pain

idea of these entities is to categorize the problems in order to gain more knowledge and create evidence to support the specific diagnosis that will develop, as the pathology is better understood. The entities are also helpful tools to compare the results of treatment as well as research.

Recently, an agreement paper has also been published regarding FAIS [16]. A similar concept of defining uniformly accepted definitions was applied for FAIS as this entity suffered from the same obstacles related to groin injuries where the terminology, the definitions, and the diagnostic criteria used for FAIS lacked consensus and uniformity. The Warwick agreement defines FAIS as a motion-related hip disorder with a combined triad of symptoms, clinical signs, and imaging findings [16].

These two papers provide a common international language and are extremely important steps to move the clinical understanding and the research of injuries in this region forward for the eventual benefit of the athletes.

18.4 Non-Traumatic and Traumatic Hip and Groin Injuries

18.4.1 Musculotendinous Injuries

Injuries to the musculotendinous structures of the groin are by far the most common type of injuries related to the hip and groin in athletes. For both acute and long-standing groin pain adductor-related injuries are most frequent, accounting for up to 64% of all hip and groin injuries [8].

18.4.1.1 Acute Groin Injuries

The most common acute injury in the groin is to the adductors, especially adductor longus, but also the iliopsoas, proximal rectus femoris, and the muscles involved in the inguinal canal/conjoined tendon are not infrequently injured [17]. The hip flexor injuries can be difficult to diagnose with clinical examination alone and imaging with ultrasound or MRI is very helpful [18]. The more common acute adductor injuries can in most cases be diagnosed clinically with no need for imaging [18]. The acute groin injuries are usually located to the musculotendinous junction, but in some cases the tendon itself or the insertion of the tendon into the bone is the site of the injury [10, 11].

There is very limited data how acute groin injuries happen in handball, but sudden change of direction and similar movements where the muscle is stretched during forceful contraction have been shown to be common causes in other sports and are known movement patterns in handball [17].

How many acute injuries develop into long-standing groin injuries is not known. It is however likely that it is important to treat the acute injuries properly and rehabilitate all relevant muscles and synergies related to the pelvis in order to avoid the injury to recur or even develop into a long-standing problem.

18.4.1.2 Adductor-Related Injuries

The clinical signs of adductor-related groin pain are tenderness at the origin of the adductor longus and/or the gracilis at the inferior pubic ramus and groin pain at the same site as with palpation or resisted adduction [8]. Decreased adductor muscle strength and groin pain on full passive abduction are also frequent signs [13]. Most athletes with adductor-related injuries can return to sport within 4–6 weeks. There is evidence that if an elite player sustains a reinjury in the groin, the recovery period for the reinjury is almost twice as long compared to the index injury, emphasizing the importance of getting the injury sorted properly the first time [19].

18.4.1.3 Iliopsoas-Related Injuries

The clinical signs of iliopsoas-related groin pain are tenderness when palpating the muscle through the lower abdominal wall and or just distal to the inguinal ligament in the triangle medial to the sartorius muscle and lateral to the femoral artery and pain on passive stretching of the muscle during the Thomas test [8]. The iliopsoas muscle is sometimes tight, and the muscle can be weak and sore when tested isometrically with 90° of hip flexion.

The iliopsoas also tend to become sensitized in patients with other kinds of hip and groin injuries. Iliopsoas-related groin pain therefore often seems to coexist with intra-articular hip problems, but is also seen coexisting with adductor-related groin problems as well as being an injury by itself [9, 20]. Whether the coexistence with other injuries represents a protective response, with increased tenderness and pain during palpation and stretching is unknown.

Ultrasound examination has been suggested as the diagnostic imaging modality of choice for determining the existence of tissue disruption in the iliopsoas, oedema, in-growth of blood vessels or calcified tissue in the iliopsoas and any US findings suggestive of specific injury to the muscle-tendon complex.

18.4.1.4 Inguinal-Related Groin Injury (Sports Hernia)

Pain in the inguinal region is sometimes referred to as sports hernia, sportsman's hernia, or likewise. Pain over the inguinal canal and the pubic tubercle often radiating to the medial groin and the scrotum are characteristic complaints. The clinical signs are tenderness at the insertion of the conjoined tendon at the pubic tubercle and pain when palpating the inguinal canal through the scrotum with the patient standing. No hernia can be palpated [8, 15]. Dynamic examination using ultrasonography can be used to visualize the weakness of the abdominal wall during maneuvers that increase intra-abdominal pressure (i.e., Valsalva). Inguinal-related groin injury is not a common injury in the groin region and only accounts for up to 4% of all injuries to the hip and groin in male elite soccer players. The injury incidence is 0.04 per 1000 h of soccer play at the elite level. It can, however, be a very troublesome condition, which takes a long time to recover from, and may not resolve by conservative treatment. The extent of this pathology has yet to be described in handball players. In elite male football almost 50% of players suffering from inguinal-related groin injury are missing more than 4 weeks training and match play, and the injury time is almost double that of the injuries to the adductors [19, 21]. It is not clear whether this is due to operative procedures keeping players out for a longer period or due to the nature of the injury itself.

18.4.2 Intra-Articular Hip Injury

Intra-articular hip injuries are the most frequent sources of groin pain in athletes that are not related to the musculotendinous structures in the groin region. The most common clinical sign of intra-articular hip pain is groin pain [22], and differentiating between intra- and extra-articular sources of groin pain therefore remains a clinical challenge. In recent years, intra-articular hip injuries have received increased recognition as an important differential diagnose in athletes with groin pain. This is reflected in the Australian Football League injury report from 2012, where the incidence of hip-related injuries seems to have gone up during the last 10 years [21]. In elite football, intra-articular hip injuries account for up to 10% of all hip and groin injuries [19]. Due to the similarities in movement patterns between football and handball, such as sudden change of directions and numerous accelerations and decelerations intra-articular hip injuries are expected to be prevalent in handball as well. The most common diagnosis of intra-articular hip pain is femoroacetabular impingement syndrome (FAIS) representing symptomatic premature contact between the proximal femur and the acetabulum [16]. As this condition may lead to associated chondrolabral pathology, synovitis, and early osteoarthritis [23], a proper diagnosis is important. The diagnosis of FAIS is based on a combined triad of subjective symptoms, clinical findings such as a positive impingement test, and imaging findings such as cam and/or pincer morphology [16]. Cam morphology represents convexity at the femoral head-neck junction, while pincer morphology represents global or focal over-coverage of the femoral head by the acetabulum [24]. There is evidence to suggest that hip loading in especially hip flexion and rotation patterns during childhood and early adolescent contribute to the development of cam morphology [25–27]. As such handball may be considered a sport with an inherent risk of developing cam morphology potentially leading to FAIS at a later stage. Especially, handball goalkeepers may be at an increased risk of developing FAIS as they often perform within a wide hip range motion compared to outfield players. Ice hockey goalkeepers, performing several similar maneuvers as handball goalkeepers, have been suggested as a population at risk [28, 29].

18.4.3 Stress Fractures, Avulsion Injuries, and Apophysis Lesions

Stress fractures in the hip and pelvis are most common in female runners but should not be missed as a possible differential diagnosis, which may present as a groin injury [30]. Stress fracture of the femoral neck, the sacrum, the pubis, and the ischium can be seen. In elite male soccer players, stress fractures constitute less than 5% of all hip and groin injuries [19].

Avulsion fractures from the pelvis are most common in the adolescent patient. The apophyses are prone to overuse or to traumatic overload causing a painful lesion. The most frequent locations in the groin and hip region are at the anterior superior iliac spine (ASIS) caused by the sartorius muscle especially during jumping activities and at anterior inferior iliac spine (AIIS) caused by the rectus femoris muscle during kicking.

18.4.4 Other Sources of Groin Pain

Bursitis either traumatic or inflammatory should also be considered. The bursae are usually localized between tendons and muscles and over bony prominences. The iliopectineal bursa was earlier considered a major contributor to groin pain in athletes. But recent imaging techniques such as ultrasound and MRI have shown that this is not the case.

Peripheral nerves may become entrapped after direct trauma or due to an overuse condition of the neighboring fascia, tendons, or muscles leading to an inflammatory condition. Nerves most commonly affected are the ilioinguinal, genitofemoral, and lateral cutaneous femoral nerves. The diagnosis can be difficult, but localized tenderness at the site of the site of penetration through the fascia is common. The pain is usually experienced with hyperesthesia or hypoesthesia of the skin along the specific nerves innervation area. The characteristics of the pain may vary considerably.

Even in seemingly healthy athletes, neoplasms should be kept in mind as a possible cause of hip and groin pain. Osteosarcomas, chondrosarcomas, and other tumors have been diagnosed often at a late stage, due to both patient’s and doctor’s delay.

In elite male soccer players which all are examined by clubs doctors and which have a professional sports medicine setup, 5–10% of the investigated hip and groin injuries are classified as non-specific groin pain [19]. This means that in these cases it was not possible to provide a specific diagnosis and that other source of pain needs to be considered.

18.5 Clinical Assessment

18.5.1 Subjective History

Obtaining a thorough history is very important: Acute or overuse injury? Direct or indirect trauma? Previous treatment? The history will often provide a good indication of where to look for the diagnosis. In some cases the history and the present symptoms leave very little doubt, and a direct examination of the relevant region will promptly reveal the diagnosis. But in other cases, a rather comprehensive examination is required. In such cases a systematic approach is imperative. It is also important to realize that even when dealing with otherwise healthy and often young individuals, more serious diseases (e.g., infection, cancer, and systemic disease) are possibilities that should be considered since this region often is hosting pain perceptions from other regions and organs. Accompanying weight loss, fatigue, fever, chills, and a history of recent infection such as diarrhea are important symptoms that could reflect a reactive synovitis in the hip, an infected hip, or a malignant condition.

If an acute episode initiated the injury, a precise description of the injury mechanism can be very helpful. Understanding if the mechanism was contact or noncontact related, the energy and forces involved in the mechanism, the exact activity and action, which generated the injury, are examples of important information relevant to reaching an accurate diagnosis. Additional focus should be directed at symptoms correlating with the timing of the injury, such as an accompanying sound or sensation (i.e., snap, click or pop), as well as whether the player could resume activity soon after the injury and the pain pattern following.

If no acute incident can be recalled, it is often helpful to look into the activities undertaken by the patient in the period preceding the injury as well as a description of the development of symptoms, such as change in the load of activity (intensity, frequency, duration) and change of equipment, surface, or technique, and if the development of problems correlated to such changes. Furthermore, information on similar previous symptoms should be noted.

A history of systemic, urogenital, abdominal, or low back symptoms should be taken as well. Childhood hip disorders such as Legg-Calvé-Perthes disease, slipped capital femoral epiphysis, developmental dysplasia of the hip and septic arthritis are important diagnosis to be aware of in the patient's history. Disorders such as rheumatoid arthritis (RA), psoriatic arthritis or ankylosing spondylitis, malignancy, or low back pain can also be part of the etiology of the hip pain. A history of alcohol or steroid use is important in patients suspected of having osteonecrosis.

The precise location of the pain can sometimes be difficult for the patient to describe, but if possible it should be identified. Characterizing the complaints is an important part of the diagnostic procedure, and apart from localizing the pain, efforts should be made to clearly recognize the nature of the pain: if the pain is provoked or alleviated by anything; if there is a radiating element to the pain; the present activity level of the patient in activities of daily living (ADL), work, and sport; and also previous treatment(s) and response to such treatment(s).

18.5.2 Physical Assessment

Physical assessment should begin with observations of static (i.e., stance, alignment) and dynamic functions (i.e., gait pattern and rhythm, climbing stairs, running) and should be done both from a frontal and sagittal planes. Trendelenburg gait is the result of insufficient muscle function in the gluteus medius and minimus and sometimes the tensor fascia lata. To unload these weakened abductors and avoid pain production, the patient often shifts the center of gravity over the affected limb during the stance phase of gait, resulting in a pelvic drop on the contralateral unaffected side and trunk shift over the affected side. Coxalgic gait is the result of the patient quickly unloading the painful leg while bearing weight. This results in a decreased stance phase and stride length during gait on the affected side. In some cases the patient has a stiff hip gait and will walk by rotating the pelvis and swinging the legs in a circular fashion. More strenuous activities such as running may need to be investigated, as activities of daily living are often not always a problem for athletes, as their problems are mainly related to athletic performance. Running should be investigated for any unloading or compensating strategies, which these patients will sometimes display due to pain.

18.5.3 Range of Motion

Active and passive range of motion with the patient in the supine position should be measured and compared with values of the opposite side. Flexion, extension, abduction, adduction, and internal-external rotation should be evaluated in both flexion and extension. Internal rotation is usually most affected in most types of arthritis (osteoarthritis and RA) as well as FAI, and this motion commonly will stimulate pain along with the limitation in range of motion. The ROM of the hip joint has been suggested as a risk factor for groin injuries [31]. There are many reasons for pathologic changes of the hip joint ROM, some of which are easily modifiable, whereas others are more difficult. Acquired tightness of the rotators, flexors, extensors, abductors, or adductors of the hip joint are all potentially able to be loosened with stretching exercises, soft tissue release techniques (manual therapy, massage, dry needling, proprioceptive neuromuscular facilitation techniques), as well as balanced muscle training addressing both the affected muscles and the antagonist muscles. One study found increased hip abduction ROM after an exercise program including both concentric and eccentric adductor exercises but no stretching exercises for the adductor muscles [32]. Generally there is no evidence that stretching can prevent groin injuries. However there are indications that a normal ROM of the muscles and joints probably is important.

In cases with cam and/or pincer bony morphology stretching could potentially lead to further structural damage to the hip joint [33]. If the impingement problem is symptomatic with hip joint and groin pain, damage to the acetabular cartilage as well as to the labrum of the hip joint may be prevalent. If this is suspected, active and passive stretching techniques should be completely avoided, as this may cause further injury to acetabular cartilage and labral structures.

18.5.4 Muscle Strength Testing

Hip strength assessment plays an important role in clinical examination of the hip and groin region. Decreased muscle strength seems to be a consistent finding in patients with hip and groin pathology [13]. Furthermore, decreased hip adduction strength in football and ice hockey players, seems to increase the risk of sustaining a groin injury [12, 34].

A reliable, inexpensive, and easy way to quantify isometric and eccentric hip muscle strength in clinical practice is by using a handheld dynamometer (HHD), which is a portable strength testing device [35]. When using the HHD, it is important to be aware of factors that may compromise its reliability, such as experience with the testing procedure and the tester's strength. In situations where the tester is unable to fixate the HHD due to decreased strength compared to the tested athlete, maximal muscle strength is no longer measured, and reliability is therefore affected [36]. In such cases an external fixation device, such as a belt, may be introduced to secure a high reliability [37].

The HHD can be used to track progression in hip muscle strength during treatment and postoperative rehabilitation. Comparison, if possible, should always be made with the contralateral healthy leg, pre-injury measurements of the affected leg if available, or using normative values, preferable from Handball players. In cases where the athlete is affected bilaterally (e.g., bilateral long-standing adductor-related pain) and comparison with the contralateral side is not suitable, the strength ratio between hip adductor and abductor may be a more relevant measure, as the contralateral leg cannot be used as a reference point. In football, and presumably also in handball, normative values suggest a hip adductor/abductor ratio of around 1.2–1.4 [38].

Another quick assessment of the hip and groin function can be performed with the Copenhagen five-second squeeze test [39]. This test is performed as the adductor squeeze test described above. The athlete is instructed to score the experienced pain in the groin region on a Numerical Rating Scale ranging from 0 (no pain) to 10 (maximal pain) subsequent to a maximum adductor squeeze for five seconds. Based on the experienced pain level, the athlete can be given a green (0–2), yellow (3–5), or red (6–10) light representing an approximation of readiness to participate in training. Such an approach has been shown to correlate with self-reported hip and groin function measured with the HAGOS questionnaire and thus can be used to provide the clinician with a quick and valid indicator of hip and groin function [39].

18.5.5 Specific Tests

18.5.5.1 Musculotendinous Pain

Palpation of the majority of the important anatomical structures can be done with the patient in the supine position, for example, the pubic symphysis, the tendons and their attachments, and the muscle bellies. Additionally, the external orifice of the inguinal canal should be palpated with the patient standing.

The palpation of the adductor insertion is done with the hip flexed, abducted, and externally rotated, and the knee slightly flexed. The examiner, using the right hand on the right leg, and left hand on the left leg, palpates the adductor longus tendon with two fingers and follows the tendon to the insertion at the pubic bone. The insertion area, including the bone, is tested with firm pressure to a radius of about 1 cm. Pain on palpation suggest adductor-related groin pain [8] (Fig. 18.1).

The iliopsoas can be palpated both above the inguinal ligament at the level of the anterior superior iliac spine (ASIS) and under the ligament, medial to the sartorius muscle, and lateral to the femoral artery. The patient is supine, and gentle abdominal palpation is performed using both hands. The fingers are gently pressed posteriorly while pushing the abdominal structures away to reach the iliopsoas muscle. The patient is then asked to elevate the leg 5 cm, and the psoas can be felt and palpated for any pain. The tendon of the iliopsoas muscle can be identified during the palpation distal to the inguinal ligament by asking the patient to elevate the examined leg 5 cm from the examination bed/table, while the fingers position is adjusted until the tendon is palpated under the fingers. Then the patient relaxes and the tendon can be palpated for any pain. If any of these palpations are painful, iliopsoas-related groin pain is suspected [8] (Fig. 18.2).

Fig. 18.1 Adductor palpation

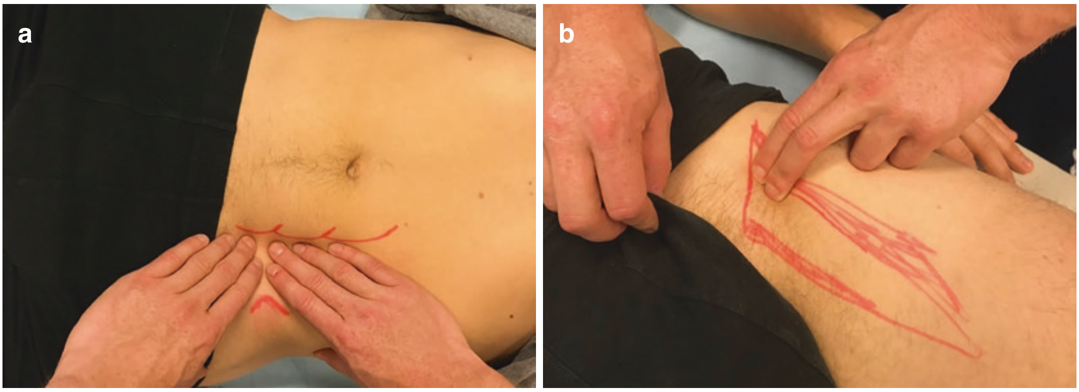

Fig. 18.2 (**a**) Psoas abdominal palp. (**b**) Psoas under inguinal ligament palp

The external orifice of the inguinal canal is approximately the size of a fingertip, and when an inguinal hernia is present, the orifice is enlarged, and the hernia contents are pushed against the finger during maneuvers which elevate the intra-abdominal pressure, such as coughing. The incipient hernia is not a true hernia, and there is no bulging. Pain when palpating the orifice and/or dilatation is a characteristic finding with an incipient hernia. When palpation of the conjoined tendon insertion at the pubic tubercle just medial to the inguinal ligament is painful, this is also a positive test of inguinal related groin pain [8, 15].

The piriformis muscle is tested in the supine position with the hip in flexion and adduction and can be stretched rotating internally. The patient will feel a pain in the inferior part of the gluteal area sometimes radiating down the lines of the ischial nerve in case of a piriformis-related pain problem.

Adductor Squeeze Test

There are a number of adductor squeeze tests, but the most sensitive is performed with the patient in the supine position. The examiner stands at the end of the treatment couch with hands and lower arms between the feet of the subject to hold them apart. The feet of the subject point straight up, and the subject presses them together with maximal force without lifting the legs or pelvis. The test is positive if it reproduces pain from insertion site of the adductor longus where the patient also was tender at palpation [8, 40] (Fig. 18.3).

Fig. 18.3 Adductor squeeze test

18.5.5.2 Femoroacetabular Impingement Syndrome

The patient usually complaints of a sharp pain deep in the groin during hip flexion, internal rotation, or abduction movements. Other symptoms such as painful clicking are not infrequently observed and may suggest involvement of the hip labrum [41]. The ability to make deep squats is often compromised as well as sudden stopping/starting and cutting movements. The patient often has decreased hip range of motion and hip muscle strength [42]. Most frequently flexion and internal rotation are the most limited motions, but external rotation and abduction can also be decreased. Hip muscle strength seems to be impaired particularly for hip flexion, extension, abduction, and adduction.

The diagnostic process of FAIS remains a challenge as specific clinical tests seem to have low diagnostic accuracy [43]. Therefore, before introducing specific intra-articular hip tests, the clinician should seek to rule out other potential causes masquerading as intra-articular hip pain [44]. This can be done by examining the musculotendinous structures in the groin (as presented above) and by using sensitive tests to rule out a stress fracture of the hip (Fulcrum Test), referred pain from the lumbar region (Repeated Motions and Extension-Rotation-Test), and pelvic girdle pain (Thigh Thrust Test) [44]. Subsequently, the **impingement test** (also known as the Flexion Adduction Internal Rotation – FADIR) should be applied to investigate for potential FAIS [16, 45]. However, it should be noted that this test is not very specific (low specificity) but very sensitive (high sensitivity) and thus positive in most of the patients having an intra-articular problem [43]. For the impingement test, the patient is supine, and the hip is passively flexed to 90º, adducted and internally rotated. This movement brings the anterior femoral neck in contact with the anterior rim of the acetabulum. This test will reproduce the typical groin pain that may be present with this condition. It is important to realize that a multiplicity of other structures will be impinged, squeezed, and compressed with this test, including the iliopsoas muscle and tendon, the rectus femoris, the inguinal canal, and the nerves and vessels in the region. It is therefore important to rule these structures out before deciding that a positive impingement test means that the radiological morphological findings are causing FAIS. A positive test is not diagnostic of an intra-articular hip joint problem, but if it is negative an intra articular hip joint problem is not likely [43].

Other tests such as hip internal rotation with/without hip flexion have also been suggested to be indicative of FAIS when range of motion is limited and end range is painful [45]. As with the impingement test, it is important to rule out other painful structures when interpreting the test (Fig. 18.4).

18.5.6 Radiology

Radiographic abnormalities are common in athletes involved in the football codes [46], in basketball, in ice hockey [47], and presumably also in handball. The current evidence of the use of radiographs, ultrasonography, and magnetic resonance imaging (MRI) is based on relatively few heterogeneous studies of varying methodological quality, and the correlation between identified radiological abnormalities and symptoms may be low (Fig. 18.5).

Standard radiographs with the patient standing with neutral pelvic tilt and 15° internal rotation of the legs and a true lateral view are in most cases very helpful to rule out other potential causes of hip and groin pain, such as femoral neck stress fractures, and are useful to determine the presence of cam and/or pincer morphology [45]. No specific radiological measures, such as

Fig. 18.4 Anterior impingement test FADIR

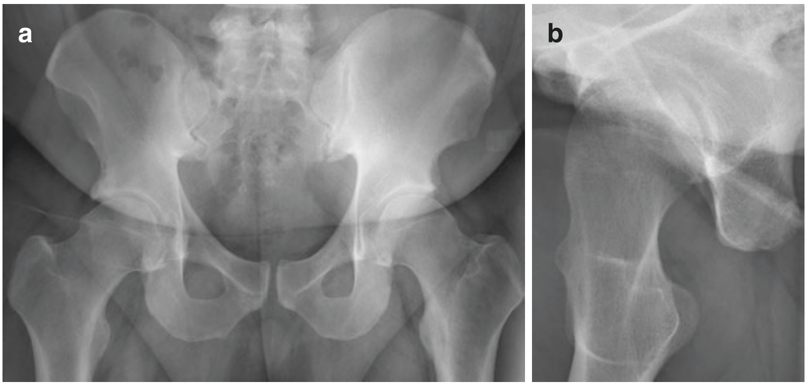

Fig. 18.5 (**a**) Bilateral cam. (**b**) Cam lateral view

the alpha angle or lateral center edge angle, can be recommended to define the presence of cam or pincer morphology, respectively [16]. Cam morphology is however often defined as an alpha angle >55° [16] measured in the Dunn view as the angle between (1) a line from the center of the femoral neck to the center of the femoral head and (2) a line from the center of the femoral head to the point where the femoral head-neck junction extends beyond the margin of the circle [24]. Pincer morphology is often defined as a lateral center edge angle >39° [16] measured as the angle between (1) a vertical line through the femoral head center and (2) a line between the femoral head center and the lateral edge of the acetabulum (Fig. 18.6) [24]. The clinician should, however, be cautious when interpreting the findings of cam and/or pincer morphology, as the prevalence of such morphologies are high in athletes regardless of symptoms [48] and in athletes with adductor-related groin pain [49]. Furthermore, poor correlation between radiological findings and pain in subjects diagnosed with FAIS has been reported [50]. If present, such morphologies therefore do not necessarily support a diagnosis of FAIS as the primary source of hip and groin pain. Standard radiographs is also valuable to assess for other potential causes of hip and groin pain, such as femoral neck stress fractures, osteoarthritis, or hip dysplasia [16]. Hip dysplasia is defined as a lateral center edge angle <20 and borderline between 20° and 25° and is of special interest as this condition too may give rise to hip labrum and/or acetabular cartilage damage [51].

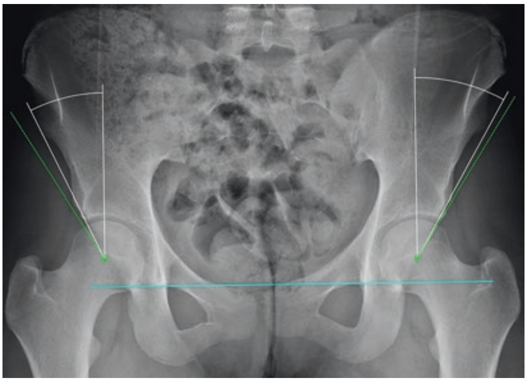

Fig. 18.6 Lateral Center Edge angle

Other imaging modalities such as MRI or ultrasonography can also be very helpful but must always be correlated carefully to the clinical situation. For intra-articular hip injuries 3.0 T MRI is considered the preferred imaging modality for identifying acetabular labral tears and chondral lesions [16]. When interpreting the MRI findings, the clinician should however be aware that the sensitivity and specificity of this modality is not perfect [52, 53]. Furthermore, acetabular labral tears may be asymptomatic [54].

An ultrasound-guided intra-articular diagnostic injection is an important aid in the examination of athletes with potential intra-articular hip injuries [16]. An intra-articular diagnostic injection may also be performed under fluoroscopy, enabling a thorough dynamic examination, a more accurate impingement site recording if and when present and potential correlation between symptoms and morphologic impingement sites. A systematic review suggested that pain relief following an intra-articular diagnostic injection supports the diagnosis of FAIS [55].

In skeletally immature adolescent players, imaging is also important to detect osseous avulsions in acute proximal or distal muscle distraction injuries and with suspicion of injury to the growth plate of the femoral neck.

The osteolytic changes including widening of the pubic symphysis and sclerosis along the rami of os pubis is often seen on X-ray and can also be seen as bone marrow edema on MRI in the pubic bone adjacent to the symphysis joint. However, this condition, originally called symphysitis or osteitis pubis, have been shown scientifically to be common also in asymptomatic footballers and thus reflect the considerable strain that the pelvic girdle is exposed to in cutting sports and is not the sign of injury.

18.5.7 Patient-Reported Outcome Measurement (PROM)

When evaluating athletes with hip and groin pain, the subjective perspective of the athlete can provide valuable information on the severity and impact of the hip and groin pain. Such information can be quantified using reliable, valid, and responsive Patient-Reported Outcome Measurements (PROMs).

For patients with hip and/or groin pain, different PROMs can be recommended based on a recent systematic review [56]. For athletes presenting with hip-related pain or undergoing hip arthroscopy for intra-articular hip pathology, the Copenhagen Hip and Groin Outcome Score (HAGOS), the Hip Outcome Score (HOS), and the two versions of the International Hip Outcome Tool (iHOT-12 and iHOT-33) have all shown sufficient reliability, validity, and responsiveness to be recommended in clinical practice.

However, HAGOS is the only PROM to date that can also be used to evaluate self-reported function in patients presenting with groin pain arising from musculotendinous structures [57]. As many athletes present with clinical signs of both hip and groin pain, HAGOS is a viable tool to monitor and track self-reported function in the daily clinic. HAGOS is self-explanatory, takes 10 min for the athletes to fill in, and consists of 37 questions divided into 6 subscales: pain, symptoms, physical function in daily living, function in sport and recreation, participation in physical activities, and quality of life. As such HAGOS measures hip and groin function in relation to different constructs, such as sport function which is highly relevant for athletes [57].

18.6 Treatment

Hip and groin injuries can be challenging to treat. However, a systematic approach using the Doha [15] and the Warwick agreements [16] combined with sound treatment principles based on science and experience often leads to good results.

Groin injuries sometimes have a tendency to become long-standing and even chronic [20]. In most cases this is probably because they are not diagnosed and treated properly early on but also because the players are in many cases able to warm up and then play in spite of the injury [58]. Playing with groin pain is a familiar phenomenon in football [58] and presumably also in handball players and could easily delay diagnosis [59]. The injury could then gradually become worse and more and more difficult to treat and at the same time secondary problems from other supporting structures may arise.

18.6.1 Acute Muscle-Tendinous Injuries

The POLICE (Protection, Optimal Loading, Ice, Compression, Elevation) protocol can be used as early treatment just like with other muscle injuries. Early mobilization including reaching the outer range of motion is recommended. In addition isometric contractions can be commenced gradually at an early stage. Within the second week, careful but more demanding lengthening contractions can be included in the rehabilitation program. Hip adduction with an elastic band could be added to increase muscular activity. This has been shown to result in significant eccentric strength gain [60]. Sports-specific drills such as running, accelerating, sprinting, change of direction, and skating can be gradually included in the program. Finally, the Copenhagen Adduction exercise should be introduced starting with 1 set of 5 repetitions on each side and gradually working toward 2–3 sets of 12–15 repetitions on each side [61]. The Copenhagen Adduction exercise has been shown to increase eccentric hip adduction and abduction strength and may also be used to increase core endurance. When performing the Copenhagen Adduction exercise, it is important that the athlete maintains a straight back and hip alignment to prevent potential back problems. Furthermore, the upper leg should be supported to avoid unnecessary stress medially on the knee [61].

Return to sport should not begin before isometric and eccentric strength as well as ROM have normalized, and sports activities such as sprinting, changing direction, forceful skating strides, and jumping exercises can be performed pain-free. It is advisable to maintain a training routine using the Copenhagen Adduction exercise after return to play, and this can easily be incorporated into the normal handball training session.

18.6.2 Long-Standing Adductor-Related Groin Pain

A randomized clinical trial has found a structured training protocol to be highly effective in the treatment of long-standing adductor-related groin pain [32]. It consists of two modules. The first module (0–2 weeks) includes specific isometric and dynamic exercises at a fairly low level of muscular activity to teach the patient to reactivate the adductor muscles. The negative feedback that is caused by the pain will in many patients result in difficulties activating the muscles.

In the second module, the exercises gradually become more demanding; resistance training as well as challenging balance and coordination exercises are included. The exercise program should be performed three times a week. The total length of the exercise-training period was between 8 and 12 weeks. No handball or other sports activities are allowed in the treatment period.

Injection with cortisone is not recommended. Various manual additional therapies can probably be used as a supplement [62].

Treatment program for long-standing adductor-related groin pain	
Module 1 (first 2 weeks)	Adductor squeeze (ball between feet), 10 × 30 s Adductor squeeze (ball between knees), 10 × 30 s Abdominal sit-ups (straight and oblique), 5 × 10 reps Folding knife (ball between knees), 5 × 10 reps Balance (wobble board), 5 min One-foot sliding board, 5 × 1 min
Module 2 (from third week)	Side-lying hip adduction/abduction, 5 × 10 reps Hip extension, 5 × 10 reps Standing hip adduction/abduction (elastic band), 5 × 10 reps Abdominal sit-ups (straight and oblique), 5 × 10 reps Cross country skiing, 5 × 10 reps Sideward motion on "fitter," 5 min Balance (wobble board), 5 min Skating (sliding board), 5 × 1 min

18.6.3 Long-Standing Iliopsoas-Related Groin Injury

As there is no evidence-based treatment of long-standing iliopsoas-related groin pain, we recommend our experience-based treatment. The iliopsoas muscle needs to gain its strength again, and a systematic and gradual strengthening program [63] including isometric, concentric, and eccentric exercises is very often effective. This specific approach targeting the iliopsoas could be combined with a more general pelvic stabilization strategy and core stability exercises.

Additional therapies like stretching and trigger point stimulation may also be helpful. In persistently painful cases, an ultrasound-guided injection along the distal iliopsoas tendon with cortisone can be helpful. This can alleviate the pain and help the athlete perform and progress with the full rehabilitation program. In only very rare circumstances, a partial iliopsoas tenotomy might be indicated. As it will leave the hip flexion strength weakened, it is not recommended in athletes.

18.6.4 Long-Standing Inguinal-Related Groin Injury (Sports Hernia)

As there is no evidence-based treatment of long-standing inguinal-related groin pain, we provide our experience-based treatment recommendation. As we consider this to be a posterior wall problem, the first line of treatment is aimed at strengthening the muscles of the inguinal canal.

The patient is prescribed with exercises for strengthening the oblique abdominal muscles as well as the rectus abdominis both in the outer and the inner range of motion. Core stability exercises challenging the balance and coordination related to all pelvic muscles should also be implemented. In many cases this will allow the strengthened posterior wall to sustain the pressure, and the compressed structures will be relieved pain-free. If the exercise therapy is not sufficient, surgical treatment with various techniques often quite similar to those used for regular hernia treatment may be advocated, with both open and endoscopic techniques available. It is imperative to thoroughly rule out other potential concomitant pathologies, which may contribute to similar symptoms before decision-making for surgery.

18.6.5 Intra-Articular Hip Injuries

In clinical situations with signs of synovitis with no sign of any intra-articular injury, this may reflect overuse and will often tend to resolve fairly quickly. In situations where specific intra-articular injuries are present, such as damage to the acetabular labrum and/or cartilage conservative management such as education, watchful waiting, lifestyle, and activity modification may not be sufficient to decrease the symptoms and allow the athlete to reuptake athletic participation [64, 65]. In such cases specific physiotherapy-led treatment and/or operative procedures may be relevant to introduce [16]. Despite no level 1 evidence for the treatment of FAIS, it is the authors' perception that structured physiotherapy-led treatment should be tried before progressing to operative procedures. The physiotherapist-led treatment should focus on restoring known impairments related to FAIS, such as decreased hip flexion, extension, abduction, and adduction muscle strength [66–71] and decreased trunk endurance strength [72]. Furthermore, emphasis should be given to functional task performance, such as single-leg hop performance, plyometric ability, and hip stability [71, 73–76].

If physiotherapy-led treatment is unsuccessful, operative procedures such as hip arthroscopy, including labral repair and cam resection, should be considered. In case of hip dysplasia with a lateral center edge angle <20° (20°–25° being borderline) and/or acetabular retroversion, care should be taken, and in most cases it is recommended to consider periacetabular osteotomy as the primary procedure. Favorable outcomes on return to play following operative management of FAIS have been reported [77]. A recent systematic review including 18 studies, primarily on high-level athletes, found that 82% return to the same level of sport compared to before the onset of hip/groin pain, while 87% return to any level of sport [77]. However, athletes presenting with severe cartilage damage or symptoms of osteoarthritis, as well as athletes competing in high-impact sports, such as handball, may return to sport at a lower rate [77, 78]. Following hip arthroscopy, it is paramount to follow a structured rehabilitation program designed to restore optimal hip muscle strength, stability, neuromuscular control, and range of motion [16]. The effect of postoperative rehabilitation has only been poorly investigated [79], but like physiotherapy-led treatment of FAIS, the rehabilitation should focus on established muscular and functional hip deficits. The athlete should work from isolated hip exercises targeting the deep hip stabilizers progressing into functional activities. Isolated strength hip exercises, such as the Copenhagen Adduction exercise [61] and hip flexion with an elastic band [63], seeking to develop significant hip muscle strength should also be emphasized to increase the load absorption capacity of the hip joint complex. During the rehabilitation process, the clinician should pay attention to, and address, potential painful competing musculotendinous structures, such as the iliopsoas muscle [80].

No return to sport guidelines exist for athletes who have undergone hip surgery for FAIS; however, the athlete should aim for leg symmetry on hip muscle strength and one-leg jump performance. Furthermore, the clinician should be aware that psychological factors such as motivation, self-efficacy, and fear of reinjury may be important for successful return to play, and indications of such potential barriers should be address if present [81].

Impairments to be addressed during rehabilitation of athletes with FAIS	
Muscular impairments	Altered coordination of deep hip muscles Decreased core muscle endurance Decreased hip flexor strength Decreased hip extension strength Decreased hip adduction strength Decreased hip abduction strength Decreased hip rotation strength
Functional impairments	Decreased single-leg balance Decreased single-leg jump performance Decreased sprint performance Decreased agility performance

18.7 Summary

Hip and groin pain is prevalent in handball players constituting up to 12.5% and 11% of all overuse and acute injuries, respectively, recorded during a full handball season. Of these, adductor-related groin pain is the most common cause of hip and groin pain. The diagnosis of groin pain related to musculotendinous structures should follow the DOHA agreement on terminology and definitions in groin pain in athletes and be based on specific palpation and muscular resistance tests. Similarly, the diagnosis of intra-articular hip pain such as femoroacetabular impingement syndrome should follow the Warwick agreement and be based on a triad of symptoms, clinical findings, and radiological findings. The treatment should focus on active rehabilitation aiming to restore and build hip muscle strength and increase pelvic stability. In cases with FAIS or isolated intra-articular hip pathology, such as labral tear and/or cartilage damage, hip arthroscpy may be considered, and favorable outcomes on return to sport have been reported in high-level athletes.

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Knee Injuries in Handball

19

Philippe Landreau, Lior Laver, and Romain Seil

19.1 Introduction

Knee injuries are frequent in handball players. They represent the most severe injuries, both because of the frequently prolonged time to return to sport and the potential consequences in the long term. One of the main and most severe injuries is the anterior cruciate ligament (ACL) rupture. A special chapter is dedicated to this topic in this book. The posterior cruciate ligament and cartilage injuries are also treated separately. We ask the reader to refer to these chapters for specific questions, knowing that it was not conceivable to discuss all knee injuries in one chapter. Therefore, deals with the main injuries occurring in handball, either for their frequency or their severity.

19.2 Epidemiology

Injuries of the lower extremities are frequent in handball players. Most epidemiological studies have shown that the majority of acute injuries in handball are located in the lower extremities, regardless of age and gender [1–3]. The most frequent injuries reported in handball are ankle injuries (8–45%), while the most severe are knee injuries (7–27%). The latter statistics—expressed as the estimated time of absence from full participation in training and match play—are influenced by the high number of anterior cruciate ligament tears. While some ankle injuries, like simple sprains, usually need only a few days to recover, an ACL injury would mostly require surgery, and a long period of rehabilitation before these patients can reach their pre-injury activity level. Langevoort et al. [4] reported that during major competitions, the incidence of lower extremity injuries in men was 42%; knee injuries represented 13% of all injuries, while 11% affected the ankle joint. A recent study by Bere et al. [5] recorded injury and illness surveillance during the 24th Men Handball World championship 2015 in Qatar. They showed that

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58% of injuries were located in the lower extremity (17% ankle, 16% thigh, and only 11% knee). The variance in injury rates which was reported in earlier and recent studies could partially be explained by the development and implementation of prevention exercises handball training. There is a gender difference in ACL injury incidence in handball, with female players suffering four to five times more often than the male athletes [6, 7].

Overuse knee injuries are probably underreported in the literature. Seil et al. [2], reported overuse knee symptoms represented 16% of all overuse injuries, not far behind shoulder injuries (19%) and low back pain (17%). In a study on injury pattern in youth team handball, Olsen et al. [8] reported that 79% of the recorded injuries were acute and 21% were overuse injuries. Knee overuse injuries represented 12% of all overuse injuries and the author mentioned that the percentage is probably underestimated as the study included injuries causing "considerable discomfort." Moller et al. reported on injury rates in 517 elite male and female senior and youth Danish handball, reporting that the knee was the most common site for overuse injuries in adults and the second most common site in youth players [9]. Clarsen et al. studied the prevalence and impact of overuse injuries in Norwegian sports, including 55 handball players [10]. They reported that the knee was the second most common site of injury for overuse injuries (20%) after the shoulder (22%); however, it was the most common site for substantial overuse injuries (8%) compared to the shoulder (6%). The knee was also the second most common site for overuse injuries (20%) after the shoulder (33%) in elite Brazilian handball players [11].

A few studies have compared knee injuries in handball and other sports [12–14]. Majewski et al. [14] documented 17.397 patients with 19.530 sports injuries in 26 different sports over a 10-year period. They reported that 39.8% of the injuries were related to the knee joint. When considering specific knee structures they reported, the highest risk for a structural lesion is seen in handball and volleyball for the ACL and in handball for the PCL.

19.3 Risks Factors

19.3.1 Intrinsic Factors

19.3.1.1 Gender

As previously mentioned, it has been extensively demonstrated in the literature that in handball, women have an incidence of ACL injury which is three to five times higher than in men [2, 7, 15]. Several factors have been highlighted as the main reasons for this difference (i.e., anatomical and hormonal factors, increased physiological knee laxity), and they are extensively discussed in subsequent chapters in this book.

19.3.1.2 Previous Injury

A few studies have shown that previous injury is a risk factor for a new injury [16]. A recently published study from the top two male divisions in Iceland has also shown that previous knee injuries were the only potential risk factor identified for knee injury [17]. Similar findings have been shown in other sports. Nevertheless, more specific handball data are needed to increase the evidence confirming previous injury as a risk factor.

19.3.1.3 Neuromuscular Status and Constitutional Laxity

There is an increased evidence that neuromuscular deficiency can increase the rate of knee injuries, especially ACL injuries. Neuromuscular training programs have proven to be efficient in preventing or at least decreasing the rate of such injuries. These training programs include activities for fitness improvement, sport-specific training and warm-up exercises, muscle strengthening, and improvement of balance and proprioception [18–20].

Physiological anteroposterior laxity and rotational laxity of the knee appear to be a risk factor for noncontact knee injuries, especially ACL injuries [21]. Therefore, players with increased physiologic laxity of the knee may be offered targeted noncontact ACL injury prevention programs. In order to avoid or at least decrease the risk of reinjury, physiological laxity of the knee should be considered when deciding on knee surgery, as well as during the course of rehabilitation and return to sport.

Handball is a sport with high risk of knee injuries; therefore, increased efforts should be directed toward primary and secondary prevention of injuries. Return to play after any knee injury should be decided after medical and physiotherapy clearance: sufficient functional scores for strength and stability and restoration of the injured limb function and core stability [22].

19.3.2 Extrinsic Factors

19.3.2.1 Floor Surface

The shoe-surface interaction is crucial for the quality of the game, but it can also play a role in the incidence of sports injuries. Due to the increased coefficient of friction, the artificial floor poses a greater risk for injuries in handball in comparison with wooden floor [23]. It has been suggested that it might be advisable to wear different types of shoes according to the floor type; however, it is important to note that since this study was conducted, floor types have developed as well as shoe technology and materials.

19.3.2.2 Player Position

Most injuries occur in the offensive part of the game as opposed to defense, when the team has ball possession and control in the opponent's half of the court [5]. Reports have highlighted certain positions to sustain more injuries [15]. Most studies have reported a higher risk for back and wing players [2, 3, 15], while some others identified line players as being be at higher risk for injuries [3, 5].

19.3.2.3 Competition vs. Practice

Although the influence of level of play in handball injuries is still debatable, there is strong evidence in the literature that injuries occur more often during match playing than during training sessions. The overall incidence of all types of injuries has been found to be 4 and 24 times higher during matches [2, 3, 6, 16].

19.4 Medial Collateral Ligament (MCL) Injuries

Anatomically, the MCL is composed of two layers, a superficial and a deep layer. The posterior oblique ligament (POL) has demonstrated to be an important valgus and rotational stabilizer of the knee. The posteromedial structures are a crucial medial knee stabilizer [24]. When making treatment decisions, it is important to consider all injuries of the medial and posteromedial structures.

MCL injuries are frequent in handball; in fact, they account for 7.9% of all sports injuries studied in 26 different types of sports [14], and they can be combined with ACL or PCL tears. Although there are few scientifically validated data on the subject in handball, experience has shown that goalkeepers are particularly at risk for this type of injury. Data from the Norwegian knee ligament registry (NKLR) showed that out of 1548 ACL injuries in handball players, 2.7% were accompanied by an MCL injury. This is comparable to the prevalence in soccer and American football but more than in basketball [12]. An additional 3.6% of handball injuries were classified as multi-ligament, meaning ACL plus at least one other ligament injury from (e.g., PCL, MCL, and/or lateral collateral ligament).

19.4.1 Mechanism of Injury and Diagnosis

There are two common MCL tear mechanisms: (1) a direct contact on the lateral part of the knee with valgus force and (2) a noncontact rotational injury with a combination of flexion, valgus, and external rotation. The noncontact mechanism is particularly common in handball, especially on artificial surfaces, when the foot is fixed on the ground and the body remains in rotation. The player usually reports a sensation of pain and a pop. This mechanism is not very specific for the severity of the injury. Immediate swelling of the knee and inability to walk are other factors of potential severity. Associated injuries, such as a cruciate ligament tear, must always be suspected.

The physical examination should include inspection in a standing position and during gait, swelling, deformity, and ecchymosis, bearing in mind that combined injuries are frequent. With the patient lying in a comfortable position, the MCL is palpated from its femoral insertion to the tibia. A valgus stress test is performed at 0 and 30° of knee flexion. An isolated laxity at 30° is indicative of an isolated lesion of the superficial part of the MCL. Laxity present at 0° of extension is a sign of severity, and an injury of other knee structures should be suspected. Hughston classified laxity in three grades [25]: grade I (laxity less than 5 mm), grade II (laxity between 6 and 10 mm), and grade III when the laxity is more than 10 mm. Theoretically, low-grade MCL injuries can be managed without any additional imaging. Stress radiographs (i.e TELOS) still have a role in higher grades of injury, for recovery assessment and in chronic cases, with easy comparison available to the non-involved side. Ultrasound is an excellent and low-cost tool for diagnosis and follow-up, however is operator dependent. However, with the availability of modern imaging and the pressure of a professional sport environment, MRI, in addition to standard radiographs, allows for an accurate evaluation of the MCL (Fig. 19.1a, b). It is important to mention that the MRI tends to overestimate the lesion, and therefore the treatment must be conducted mainly on the results of the clinical examination [26]. In case of severe medial laxity in full extension, MRI will help the surgical decision-making by allowing for an accurate evaluation of the MCL (proximal or the more rare distal MCL tear, which if a complete tear, could result in a 'stener like lesion') and potential associated meniscus injuries.

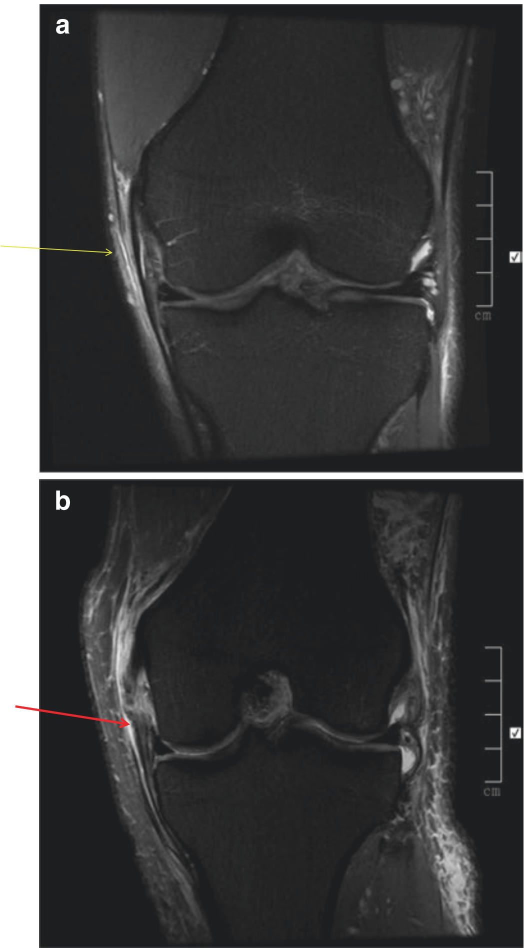

Fig. 19.1 (**a**) MCL sprain grade I. (**b**) Complete tear of the MCL, grade III (Courtesy Dr Maryam Rached AI Naimi)

Some patients may present with chronic MCL injury, complaining of medial knee pain and instability during sports activity. The clinical examination and evaluation of the lesion are the same as with acute injuries. In chronic cases, radiographs must be obtained to rule out a bony lesion or a Pellegrini-Stieda ossification. MRI should be performed for a more accurate soft tissue assessment.

19.4.2 Treatment

The majority of isolated MCL tears are treated conservatively. Grade I injuries (sprain) are treated with RICE and a hinged knee brace for a few days until pain and swelling have improved. Early physiotherapy usually allows the handball player to return to sport within 2–3 weeks after injury, ideally with a functional brace for protection and controlled progression of range of motion. A similar treatment is applied for grade II sprains, with the exception that the brace is applied for up to 3 weeks in order to allow the pain to disappear. For this reason, the recovery of strength and proprioception may take longer. The athlete can usually return to play 6 weeks after the injury.

Nonoperative treatment of grade III MCL injury takes longer. In these patients, it is important to protect the knee throughout the healing process with a hinged brace. Special attention should be given to patients with valgus alignment. The minimum period of immobilization is 4 weeks. During this time, the same protocol of physiotherapy will be applied with control of valgus loading. The main factors for guidance are pain and swelling. Rehabilitation must be more cautious in the presence of a posteromedial knee lesion. Immobilization is gradually discontinued between the 4th and 6th week. During the following 3–6 weeks, the patient can start progressive rehabilitation and sport-specific exercises. Return to sport is rarely possible before 10 weeks in a grade III injury.

Some authors have proposed platelet-rich plasma (PRP) to facilitate and improve the healing process [27]; however no studies were done on humans to our knowledge.

There are still controversies over the place of surgical treatment in isolated grade III MCL injuries [28] in an athletic population. The nonoperative management of a complete tear of the medial structure, including the POL, may lead to residual rotational instability, especially in a pivoting sport like handball. It is then crucial to identify posteromedial lesions either clinically or with MRI scan. When surgical treatment is chosen, diagnostic arthroscopy is performed first in order to assess the intra-articular structures, including the medial meniscus and the site of the deep MCL injury. An open medial approach allows for repair of the deep and superficial MCL, as well as the POL. In patients with chronic MCL injury, who complain of pain and instability in valgus, surgical treatment must be considered for reconstruction of the MCL and POL, after carefully ruling out any associated injuries.

19.5 Lateral Collateral Ligament (LCL) and Posterolateral Corner (PLC) Injuries

Like in other sports, isolated LCL and PLC injuries are generally less frequent than MCL injuries in handball. However, the true incidence is not well known as these injuries are sometimes misdiagnosed and therefore underreported [29]. Their incidence is much higher when they are combined with other ligamentous lesions such as ACL or PCL injuries and may be present in up to 40% [30]. The accurate clinical diagnosis of knee injury in handball is crucial. Misdiagnosis can lead to ineffective treatment and chronic lateral and posterolateral laxity, potentially jeopardizing the athlete's career. In addition, ACL or PCL reconstruction surgery may be compromised if lateral and posterolateral lesions are neglected.

19.5.1 Anatomy and Biomechanics

The LCL, which is also known as the fibular collateral ligament, is attached on the femur, posteriorly to the lateral epicondyle and distally on the fibular head. The PLC consists of various structures including the LCL, the popliteus tendon (PT), the popliteofibular ligament (PFL), and the posterolateral capsule which is reinforced by the arcuate ligament (AL). The PLC serves to resist varus angulation, external tibial rotation, and posterior tibial translation [31, 32] (Fig. 19.2).

19.5.2 Clinical Diagnosis

During clinical examination, the injured knee must always be compared to the opposite knee since some players have physiological lateral laxity without any symptoms. It is important to do a thorough knee examination after any handball knee injury, especially to detect the presence of a posterolateral laxity. In most patients, the cause of this type of injury is a noncontact mechanism, combining hyperextension, varus, and external rotation. But in some cases, it can be the result of a direct medial trauma. This kind of injury mech-

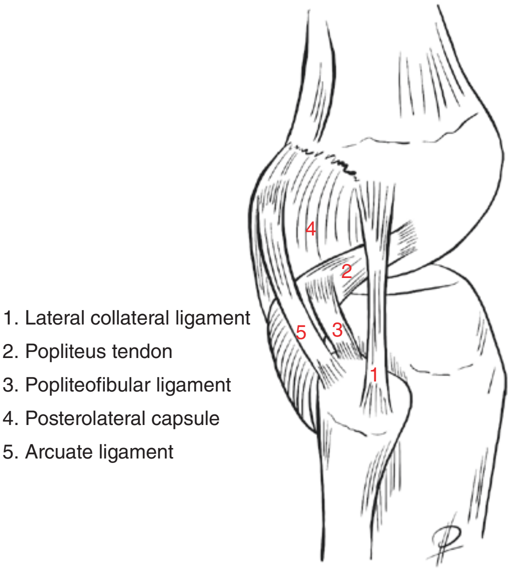

Fig. 19.2 Simplified anatomy of the posterolateral corner of the knee

anism can cause either isolated or combined ACL and PCL injuries. The trauma cascade can reach until the worst case of a knee dislocation. Some of them may be missed because they reduce spontaneously on the field. Combined vascular and/or neurologic injuries must always be suspected with these major severe knee injuries. The clinical examination must focus on assessing the integrity of the peroneal nerve and the popliteal vessels. Limb alignment must be assessed, especially if a varus deformity is present. Gait may be easily assessed in chronic cases. In an acute setting, it can be analyzed at best a few days after the injury. It will provide information about any dynamic varus alignment or the combination of hyperextension and varus deformity during the stance phase.

LCL and PLC injuries should be suspected in the presence of swelling, ecchymosis, and tenderness at the posterolateral aspect of the knee, hyperextension of the injured knee, varus laxity at 30° of knee flexion (LCL tear), varus laxity at 0° of knee flexion (suspicious for PLC injury and cruciate ligament injury), a positive dial test (more than 10° of side-to-side difference in external rotation, suggesting a PLC injury), external rotation recurvatum test (external rotation of the tibia when the knee is in hyperextension), posterolateral drawer test (suspicion of popliteal tendon and popliteofibular ligament injury), and reverse pivot shift test (reduction of the posterior subluxation of the lateral tibial plateau when the knee returns close to extension) [33] (Fig. 19.3).

19.5.3 Imaging Assessment

Standard radiographs are performed to exclude any bony avulsion or combined fracture. Stress radiographs are used by some centers for objective laxity assessment [34]. MRI provides the best imaging assessment of the posterolateral structures, allowing an accurate evaluation of the lesion, which is especially important for preoperative planning.

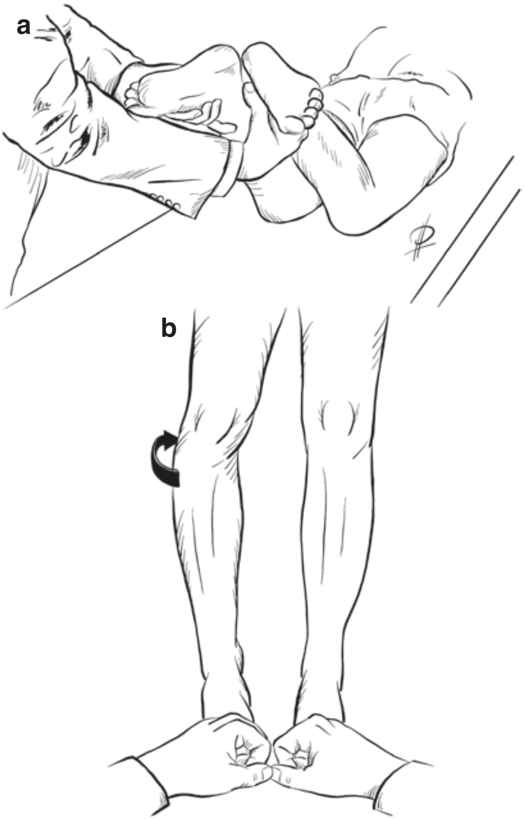

Fig. 19.3 (**a**) The dial test. More than 10° of external rotation in the injured knee compared to the uninjured, suggests PLC injury. (**b**) The recurvatum test: external rotation and varus of the tibia when the knee is in hyperextension

19.5.4 Treatment Decision-Making

The decision between conservative and surgical treatment depends on multiple factors such as the degree of laxity, knee alignment, combined injuries, the time passed from injury, and the level of the handball player. One of the most popular classification systems has been proposed by Hughston [35]. It is easily applicable in clinical practice and is based on the degree of laxity (grade I, 0–5 mm; grade II, 5–10 mm; grade III > 10 mm). Laxity must always be compared to the opposite knee. There is some consensus about the treatment of grade I and III lesions with the first being treated conservatively and the latter surgically. The treatment decision-making with grade II is more difficult, and each case must be evaluated separately taking into consideration the factors mentioned previously. Conservative treatment consists in a short period of immobilization to allow the pain and swelling to decrease. Physiotherapy can be started after a few days. Return to play can usually be considered at 8–12 weeks after injury. Surgical repair for acute grade III injuries should be performed within the first 2 to 3 weeks after injury. By then, the hematoma and swelling have decreased and soft tissue scarring still allows to identify the injured soft tissue structures. Efforts must be done to avoid missing this window of opportunity to treat these lesions by primary repair which has shown better results than chronic repair or reconstruction [36]. Some authors advise to wait until 5 or 6 weeks after a period of rehabilitation in order to decrease the risk of arthrofibrosis. There is currently a debate on the ideal treatment approach, because some of these lesions are difficult to repair. Therefore, some authors propose reconstructions instead of simple repair procedures, both in acute and chronic settings. Particular attention must be given to restore the LCL, the popliteus tendons, and the popliteofibular ligament, as these three structures seem to be the most important static stabilizers of the posterolateral side of the knee. It has been shown that persistence of varus alignment after posterolateral knee repair or reconstruction can lead to failure. Therefore, the accurate assessment of the varus before surgery is mandatory. In case of a significant malalignment, a high tibial osteotomy (HTO) may be considered, either isolated or in combination with a posterolateral ligament reconstruction. However, return to high-level sports has rarely been reported after HTO in such cases. The surgery can be done in one or two stages. In two-stage procedures, HTO is recommended first. A secondary ligament reconstruction procedure may be added after consolidation. In some selected cases, HTO can provide sufficient knee stability, especially in low-demand patients [37].

19.6 Meniscus Injuries

Meniscus injuries are common in handball. Their function is crucial, especially for sporting activities. Partial or total loss of the meniscus leads to biomechanical abnormalities which may significantly affect sports careers in the short and long term. An in-depth comprehension of their anatomy and their biomechanical role is essential to understand their function and to decide on the best treatment in handball players.

The two menisci are semilunar and wedge-shaped fibrocartilaginous structures located between the femur and the tibia. Their congruence with the femoral condyles and the tibial plateau, as well as their connection with some capsuloligamentous knee structures, plays an important role in providing biomechanical function of the knee. Their histological constitution allows to understand their mechanical role. Large collagen fiber bundles run longitudinally from the anterior to the posterior horn where they are fixed to the tibial plateau. These insertional zones are called meniscal roots. The bundles are tied together by radial fiber bundles. The main function of the meniscus is shock absorption which is achieved through a transformation of axial compressive loads into radial forces. On the surface of the meniscus, collagen fibers of a smaller diameter are arranged randomly to disperse the shear stress induced by the flexion and extension of the joint. The space between the fibers is filled with cells and an extracellular matrix made of proteoglycans and glycoproteins. The blood supply of the menisci comes from their periphery, and only the outer 30% of the meniscus is vascularized [38]. The meniscus is divided into three zones: the vascularized red-red zone is located in its periphery, providing good healing potential after repair, the red-white zone has intermediate vascularity, and the white-white (central) zone is avascular. The medial meniscus is longer than the lateral meniscus in the anteroposterior direction, and it covers 50% of the medial tibial plateau. The lateral meniscus covers 59% of the lateral tibial plateau [39]. The lateral meniscus carries most of the load transfer on the lateral compartment, while the load transmission in the medial compartment is more distributed between the cartilage surface and the medial meniscus [40]. Both menisci provide joint congruency, load transfer, pressure distribution, impact absorption, secondary stabilization, joint nutrition, and lubrication.

The surface of the lateral tibial plateau is convex, whereas the medial side is concave. For this reason, lateral meniscectomy will result in proportionally greater contact stress and higher risk of cartilage damage and osteoarthritis compared to the medial compartment [41]. The role of the menisci as secondary knee stabilizer is well recognized [42]. The posterior horn of the medial meniscus acts as a brake to control anterior tibial translation, and the lateral meniscus has a role in controlling internal tibial rotation [42, 43].

19.6.1 Epidemiology, Mechanism of Injury, Symptoms and Physical Examination

Meniscal injury was recently reported to be the most common musculoskeletal injury, with a frequency of 23.8/100000 per year [44]. Medial meniscus tears are more frequent than lateral meniscus injuries in handball players. The treatment approach greatly differs, depending on the type of injury. It is crucial to differentiate between an acute meniscus injury after a traumatic event (which is frequent in handball players) and degenerative meniscus lesions (which are more common in older players).

The most common mechanism of meniscus injury is a twisting movement, generating torsional or axial loading, including valgus and external rotation of the tibia. This mechanism can also cause an ACL tear at the same time. Another typical mechanism is the transition from hyperflexion to extension with entrapment of the meniscus tissue between the femur and the tibia. Clinically, acute tears present with sudden pain, which is usually located on the joint lines. Patients may present with effusion, but this is not specific for meniscal lesions. They can report mechanical symptoms, such as intermittent or permanent intra-articular clicking or true locking of the knee.

In case of degenerative lesions, symptoms are of a more chronic nature. The player often reports recurrent pain with effusion, typically in the absence of an injury. The presence of mechanical symptoms such as clicking and locking is important to be noted, because it can influence the treatment decision. Some degenerative meniscus lesions are asymptomatic, and they may be identified accidentally on MRI which may be performed for another reason. They should be left alone.

A meniscus tear must be suspected particularly when the patient reports pain localized along the joint line, provoked, or increased by hyperflexion, directional change during walking, crossing legs when seated, or when catching one’s foot on an irregular surface. The patient often complains of mechanical symptoms such as “clicking” or “catching,” recurrent effusion or “locking” with mechanical block to extension.

When a meniscus tear is suspected, the physical examination should include assessment of gait, mobility, laxity, limb alignment, evaluation of effusion, as well as assessment of the patellofemoral joint. This general examination should be followed by specific meniscus tests [45]:

- **Joint line tenderness on palpation** typically reproduces pain or discomfort.
- The **McMurray test** is performed with the patient in a supine position; the knee is extended from fully flexed position while internally rotating the tibia. The test is repeated while externally rotating the tibia. The aim of this maneuver is to impinge the meniscus between the femur and the tibia. Tenderness and/or crepitation along the joint line indicates a positive sign (Fig. 19.4).
- The **Apley test** is another test causing meniscus compression and grinding between the two bones. The patient is lying in a prone

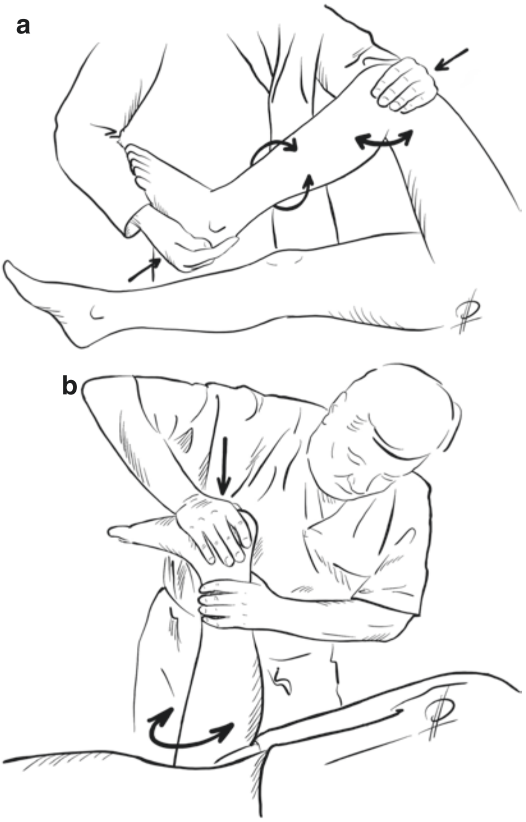

Fig. 19.4 (**a**) The McMurray test. (**b**) The Apley test

position with the knee flexed at 90°. The tibia is compressed on the distal femur, rotated externally and internally to assess the medial and lateral meniscus. This test is considered positive if it produces pain which is less severe or relieved when the maneuver is repeated with distraction of the tibia.

- The **Thessaly test**. This test has been described more recently [46]. The patient is in single-leg stance, flat footed on the affected knee. Under assistance of the examiner, the patient axially rotates the knee several times in 5 and then 20° of knee flexion. The test is considered positive when it provokes medial or lateral joint line pain or mechanical symptoms.

Among these tests, the joint line palpation has been identified as the most sensitive and specific for isolated meniscus pathology during the physical examination [46, 47]. The Thessaly test has been shown to stipulate high accuracy, but the evaluation of this test is still quite limited [46].

19.6.2 Imaging

In most cases, history and physical examination would allow to suspect isolated meniscal pathology. Nevertheless, it must be confirmed by imaging assessment; plain radiographs combining weight-bearing AP, lateral, and Merchant patella view should be the first line in an imaging study. The 45° PA weightbearing view is also highly recommended. Any sign of an early stage of osteoarthritis may indicate the presence of a potential degenerative meniscal tear.

MRI is the most accurate imaging assessment in the diagnosis of meniscal lesions [48], and it is noninvasive. It allows visualizing not only the meniscus but the surrounding soft tissue and capsular ligament as well as assessing the cartilage and the subchondral bone. High signal within the meniscal substance indicates meniscal pathology. An increased internal signal ending at one of the articular surfaces of the meniscus is a strong indicator of a meniscal tear. The specificity of this sign is improved if the increased signal is visible on more than one adjacent image [49].

The sagittal, coronal, and axial sequences usually allow defining the shape of the tear: vertical, horizontal, radial, or the classic bucket handle tear with double PCL sign where the displaced meniscus tissue appears as a second line parallel and anterior to the PCL (Fig. 19.5).

The imaging diagnosis of posterior meniscus root tear can be more challenging [50]. Posterior lateral meniscus root tear usually occurs in association with ACL injuries. Posterior medial meniscal root tears are often of degenerative nature, but they can be observed with isolated axial compression and torsional trauma as well as in cases of multi-ligament injuries. In case of posterior root tear, the MRI may show anteromedial meniscal extrusion and sometimes the classical "ghost sign" (absence of the posterior

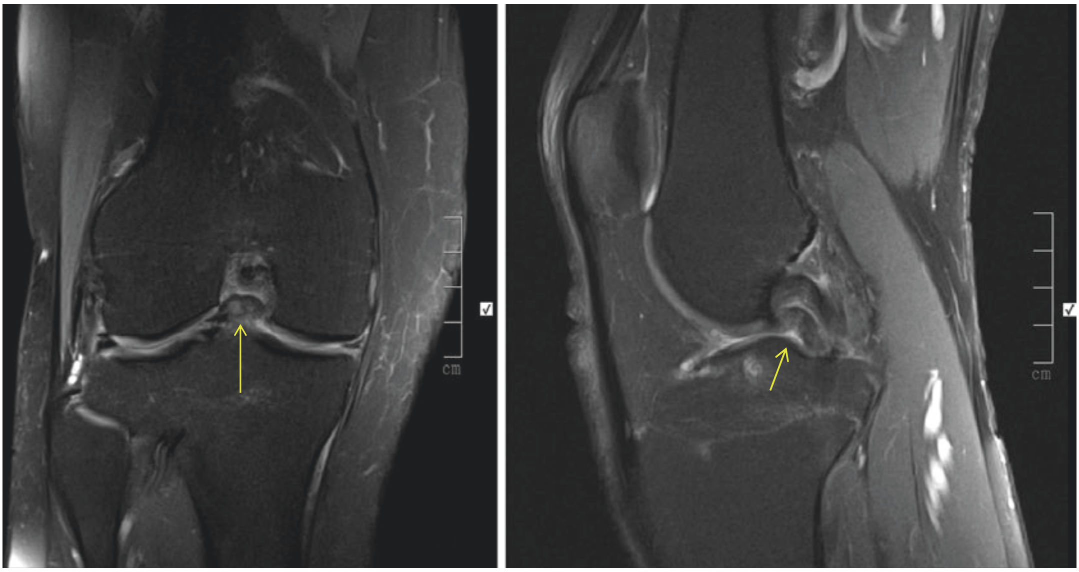

Fig. 19.5 Bucket handle tear of the medial meniscus with (**a**) Meniscal fragment visible in the notch on coronal view. (**b**) "Double PCL sign" on sagittal view (Courtesy Dr Maryam Rached AI Naimi)

horn of the medial meniscus) (Fig. 19.6). The axial view can show a linear defect at the bony insertion of the meniscal root.

19.6.3 Treatment

Even if meniscectomy is still frequently performed, recent studies are in favor of meniscal repair over partial meniscectomy, when considering clinical outcome and risk of osteoarthritis [51]. For the reasons already mentioned previously (load transferred by the lateral meniscus in comparison with the medial meniscus), the effect of a lateral meniscectomy is less "forgiving" than a medial meniscectomy. It explains that the delay of return to sport is longer after lateral meniscectomy and the risk of further osteoarthritis more important. Therefore, meniscectomy should be considered with great care, especially for the lateral meniscus. Paxton et al. [51] concluded in his study that whereas meniscal repairs have a higher reoperation rate than partial meniscectomies, they are associated with better long-term outcomes. Therefore, the concept to "save the meniscus" must be followed, especially in young handball players. Choice of treatment will depend on age, activity level, location, size, tear pattern, chronicity of the tear, combined injuries (ACL injury), and potential healing.

Fig. 19.6 Posterior medial meniscal root avulsion with the "ghost sign" (absence of the posterior horn of the medial meniscus) (Courtesy Dr Maryam Rached AI Naimi)

Meniscus lesions which are localized in the red-red zone should be repaired. This is especially true for those lesions which are repaired in conjunction with ACL reconstructions, because they have a higher healing potential than isolated repairs. In cases of lesions in the white-white zone, simple partial meniscectomy is usually performed. With lesions in the red-white zone, treatment decisions can be more challenging. Healing of these lesions could be promoted using different methods, like perforations or trephinations reaching into the vascularized area and potentially encouraging cell migration to the tear site. Fibrin clot can be used in combination with rasping of the vascularized parameniscal synovium. More recently, platelet-rich plasma has been used to improve the meniscal tear healing [52], but evidence of its efficiency is still lacking. Vertical and bucket handle tears are usually easily repairable. Small radial tears are considered as non-repairable. Complete radial tears induce a complete loss of the biomechanical function of the meniscus. Therefore, repair must be attempted especially in young players, even if it is a challenging procedure [53]. Horizontal cleavage tears have been classically resected. However, some recent studies have shown that repair can lead to good subjective and objective results in the short and long term [54]. Traumatic root tears, which are more often observed in the lateral compartment in combination with ACL tears, should be repaired in young patients. Transosseous tunnels or an all-inside technique can be used [50]. Meniscus replacement, either by meniscal allograft transplantation or by a scaffold, is usually performed in cases of chronic, total, or partial meniscus defects. These situations can occur at the end of the handball player's career, and currently there is no evidence that surgical procedure can allow professional handball players to return to the same level of sport [55].

19.6.4 Result and Return to Handball After Meniscus Repair or Meniscectomy

Partial meniscectomy provides good short-term results, and athletes usually return to pre-injury level of performance. However, results seem to deteriorate with time especially concerning the lateral meniscus [56]. It has been shown that all-inside meniscus repair can provide long-term protective effects even if the initial healing is incomplete [57]. In general, healing rates after meniscus repair are complete in 60% of the cases, partial healing in 25% of the cases, and failure in 15% of the cases [57]. Therefore, meniscus repair must be attempted if there is a potential for meniscus healing. The treatment decision can be challenging, especially in high-level professional athletes as the return to sport after an isolated meniscus repair is longer (minimum of 4 months) as compared to partial meniscectomy. The risk of lower, medium-term results after meniscectomy must be clearly communicated to the athlete, his or her medical team, and the coach. In cases when a meniscus tear is addressed during ACL reconstruction, only clearly irreparable meniscus lesions must be resected during the ACL reconstruction. The reason for this is that the rate of meniscal healing is high when performed in conjunction with intra-articular ACL reconstruction [58].

19.7 Quadriceps and Patella Injuries

19.7.1 Quadriceps and Patellar Tendinopathy

The "jumper's knee," a classic term for quadriceps and patellar tendinopathies, was described by Blazina in 1973 [59]. This pathology is common among athletes involved in jumping activities, and it is more often seen in a male than in a female population. It is particularly frequent in volleyball players (40%). In female handball players, the reported prevalence was 10%, compared to 30% in male players [60]. So far, no specific morphological risk factor has been identified for this pathology. But it has been shown that extrinsic factors play a role in the incidence of quadriceps and patellar tendinopathy, overuse being a major risk factor for tendinopathy. It appears that the field type and a player's higher explosive strength can be a risk factor as well [61].

Fig. 19.7 Proximal patellar tendinopathy (Courtesy Dr Maryam Rached AI Naimi)

The main symptom of jumper's knee is pain. Three pain locations have been observed in sports, the patellar tendon insertion on the distal pole of the patella (70% of the cases), the distal attachment of the quadriceps tendon on the superior pole of the patella (20%), and less frequently on the distal attachment of the patellar tendon (10%) (Fig. 19.7).

Standard radiographs can show insertional calcifications. MRI shows modifications of the intratendinous signal close to the insertional site. Ultrasound has become more popular in the assessment of tendinopathy, with the added value of allowing evaluation of the tendinous vascularization.

Treatment of jumper's knee is mainly conservative. Nonsteroidal Anti-inflammatory Drugs can be used in the acute phase, although corticosteroid injections were commonly used in the past [62]. Due to the high risk of tendon rupture, they are currently not recommended. Other treatment modalities have been proposed such as PRP injections, shockwave therapy, laser, and magnetic therapy although further higher level of evidence studies is necessary to properly evaluate their effects [63]. Currently, physiotherapy is the gold standard in the treatment of jumper's knee with special emphasis on eccentric exercises [64]. Surgery should be considered only after failure of conservative therapy. The objective of surgery is to induce and promote healing in the pathological area of the tendon. Common procedures vary and can combine splitting of the tendon fibers, partial disinsertion, tendon scarification, patellar drilling, and resection of the pathological tissue. The procedure can be performed either open or arthroscopically [65]. Surgery is followed by a short period of immobilization and early physiotherapy. Return to sport may be expected around 4–6 months after surgery.

19.7.2 Patellar and Quadriceps Tendon Rupture

Patellar tendon rupture can be the ultimate consequence in the spectrum of chronic patellar tendinopathy [66]. The athlete usually feels a sudden sharp pain and sensation of tear/rupture in the anterior part of the knee, usually while jumping or landing. There is a complete loss of function, followed by severe effusion and ecchymosis. It is not always preceded by the typical jumper's knee symptoms; however, these should be assessed when obtaining patient history. The diagnosis of patella tendon rupture is based on clinical examination and history. It is also important to inquire about previous intra-or peritendinous corticosteroid injections. Evidence of a palpable gap between the patella and the tibial tuberosity confirms the diagnosis. The patella often appears more proximal when compared to the contralateral knee, and the patient is unable to actively extend his knee due to extensor mechanism insufficiency. Prior to surgery, ultrasound or MRI is recommended to confirm the diagnosis and to allow for a better understanding of the tear pattern.

Quadriceps tendon ruptures have a similar clinical onset but are more frequent in older athletes. The clinical symptoms are similar, but the tendinous gap is either visible or palpable proximally to the patella. Care should be taken not to miss the diagnosis in those patients with partial quadriceps tendon tears and an incomplete functional loss of the extensor mechanism. These patients are still able to actively extend the knee but with less power than normal. Radiographs show a high-riding patella in cases of patella tendon rupture and patella baja if the quadriceps tendon is torn. Ultrasound and MRI usually confirm the diagnosis and provide more information about the quality of the tendon. Surgical repair is mandatory in case of a complete tear. It consists of suture of the tendon combined with transosseous fixation. In the postoperative period, it is recommended to immobilize the knee in full extension for 6 weeks. Initiating physiotherapy will depend on the quality and strength of the surgical repair and should be prolonged until return to sport, which is rarely possible before 6 months [66].

19.8 Patellofemoral Instability

Patellar instability is defined as an abnormal movement of the patella in the patellofemoral groove. It is characterized by subluxation or true dislocation in the coronal plane, predominantly in the lateral direction. Patients with recurrent episodes of patellar instability are found to have specific risk factors. Acute patella dislocation represents 2–3% of all knee injuries [67]. The literature reports recurrence rates of 15–60% [68].

19.8.1 History

The mechanism of injury can be a direct trauma on the medial part of the knee, but it is due more frequently to an indirect injury combining rotation, quadriceps contraction, and valgus. The patella often reduces spontaneously with extension of the knee. Sometimes the patient can reduce it himself by pushing it back into place, or assisted reduction is required. Such trauma is usually followed by swelling and pain.

19.8.2 Risks Factors

Handball by itself is a risk factor due to the frequently sustained contact and noncontact injuries with this kind of sport. Patella dislocations are more common in adolescence and young adults. The peak incidence of patellar dislocation is between 15 and 19 years of age [69]. Females seem to have a higher risk for patella dislocation than males [68].

19.8.2.1 Osseous Factors

A valgus knee increases the lateral force vector on the patella. An increase of femoral anteversion combined with external tibial torsion will also increase this laterally directed force. The patella is a sesamoid bone which is stabilized medially and laterally by the two surfaces of the femoral trochlea. The lateral trochlea ridge is larger, more proximal, and more anterior than the medial trochlea, and it prevents lateral patellar excursion. Anatomical variations such as trochlear dysplasia, meaning a shallow, flattened, or even convex trochlear groove and hypoplasia of the lateral femoral condyle decrease the control of the lateral displacement of the patella. Patella alta is another risk factor as the patella engages in the trochlea quite late during knee flexion. An abnormal lateral position of the tibial tuberosity with its patellar tendon attachment will contribute to the lateral displacement of the patella.

19.8.2.2 Soft Tissue Factors

The medial patellofemoral ligament (MPFL) is a retinacular band of tissue located between the superomedial aspect of the patella and the medial femoral epicondyle. This anatomical structure is a primary restraint of lateral patellar displacement, especially during the first degrees of flexion. It is frequently damaged during the first episode of lateral patellar dislocation. A slack MPFL will be a risk factor for recurrent patellar dislocation. The vastus medialis obliquus (VMO) is an important dynamic medial patella stabilizer. Weakening of this muscle can predispose to lateral patellar dislocation. It should therefore be strengthened during physiotherapy for lateral patellar instability [70].

19.8.3 Clinical Examination

Clinical examination after an acute episode of patellar instability can be difficult. Knee range of motion is quite often limited due to pain and effusion which that can be significant. Aspiration of the hemarthrosis facilitates the physical examination and confirms an intra-articular injury. The area around the MPFL and the medial border of the patella are usually painful during palpation.

In cases of chronic instability, the patient must be assessed in a standing position and observed for morphological abnormalities including genu valgum, hindfoot valgus, pronation of the foot, and malposition of the patella or "squinting patella." Gait and rotation of the hip joint must be analyzed as well.

There are several clinical tests that can suggest patellar instability. During the **apprehension test**, the patella is pushed laterally by the examiner. In case of patellar instability, the patient would have a sense of apprehension. For the **J-sign**, the patient is asked to actively extend his knee from 90°. The test is considered positive if the patella shifts suddenly laterally as it goes over the proximal edge of lateral trochlea ridge. The **patella glide test** is performed with the knee in full extension and relaxed quadriceps. The patella is translated in the mediolateral direction by the examiner. The displacement is quantified with the quadrant method and must be compared to the opposite knee to evaluate the significance of lateral patellar displacement.

19.8.4 Imaging

Radiographs, including standing AP, lateral views at 30° of knee flexion, as well as sunrise view, are valuable in detecting patella subluxation, osteochondral fractures, or dysplasia. The lateral radiograph in particular allows to evaluate the height of the patella and identify trochlear dysplasia. A "crossing sign" has been shown to be present in 96% of patients with history of true patella dislocation [71]. The classification of trochlear dysplasia has been described by Dejour based on the information provided by lateral and axial radiographs [71] (Fig. 19.8). MRI is a useful tool in assessing soft tissue, including the MPFL and cartilage surfaces. Following an acute episode of patellar instability, MRI usually shows bone marrow edema on the lateral femoral condyle and medial patella border [72]. Computed tomography (CT scan) allows bone assessment, especially trochlear dysplasia and shape of the patella. It may be used to quantify the lateralization of the tibial tuberosity, defined by the TT-TG distance [71]. A TT-TG distance greater than 20 mm is frequently associated with patella instability. The value of the TT-TG distance is taken into consideration in the preoperative planning of tibial tuberosity osteotomy.

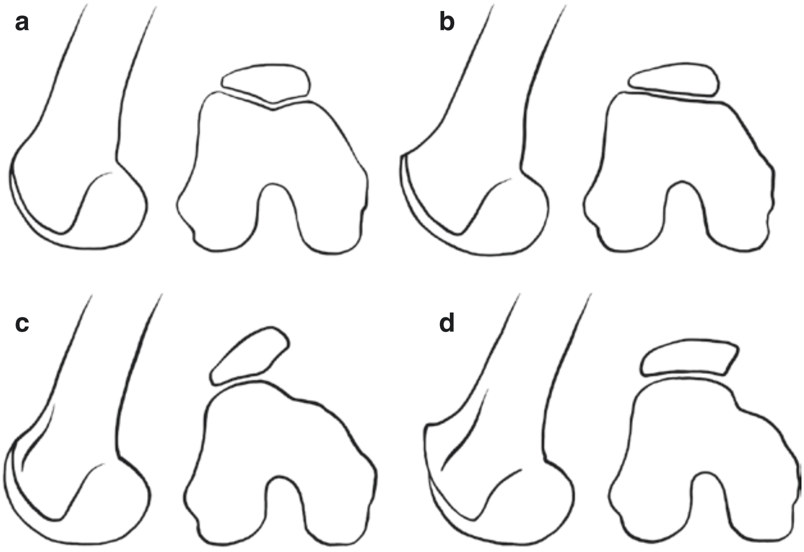

Fig. 19.8 Trochlear dysplasia classification of Dejour. Type A: Crossing sign, shallow trochlea >145°. Type B: Crossing sign, supratrochlear spur, flat or convex trochlea. Type C: Crossing sign, double contour (projection of medial hypoplastic facet). Type D: Crossing sign, supratrochlear spur, double contour, cliff sign

19.8.5 Treatment

Currently, there is no consensus concerning the management of a first traumatic patella dislocation [73]. The knee is usually immobilized in a brace after aspiration of the effusion, and early physiotherapy is recommended. Return to sport will depend on muscle recovery, patella control, and proprioception. Knee arthroscopy can be indicated in case of a displaced osteochondral fracture.

Different techniques have been proposed for the management of chronic instability, but there is still some lack of consensus in the literature [74]. MPFL reconstruction is currently the most popular surgical procedure. Tibial tubercle transfer procedures, including osteotomy of the tibial tubercle and medializing and/or distalizing its position (commonly a combination of both), can be used to correct increased TT-TG distance or patellar height issues. Trochleoplasty procedures can offer reshaping of the trochlear groove and may be considered in some selected cases of severe trochlea dysplasia. In the rare cases of abnormal rotational profiles of the lower limb (i.e., femoral anteversion; tibial external rotation), a de-rotational osteotomy may be considered. It is important to note that the effect of these procedures in handball players and their ability to return to sport has not been studied and is thus not known. The management algorithm of patellar instability in handball players should therefore be based on the risk factors, history of patellar instability, and level of sport [75]. Return to handball after surgical treatment depends on several factors including the importance of risk factors and type of surgical treatment. The delay is rarely less than 6 months. The percentage of patients capable to return to play has been reported to be higher than 90%; however the return to their pre-injury level of sport varies widely and is generally considered much lower (32–82%) [75].

Conclusion

Knee injuries, either acute or overuse injuries, are frequent in handball. Some of them are severe, like the ACL/PCL tears, some posterolateral injuries, or quadriceps/patellar tendon ruptures where the time to return to play after treatment is usually more than 6 months. Meniscus tears should not be underestimated as their incorrect treatment can compromise a player's career. Any acute or overuse knee injury in handball must be accurately evaluated, using a cautious clinical examination and imaging, in order to provide the best treatment for return to sport to the same level.

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Management of ACL Injuries in Handball

20

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20.1 Extent of the Problem

The most frequent severe knee injury in sports is an anterior cruciate ligament (ACL) tear. The ACL is a primary restraint to anterior tibial translation and participates in the control of knee rotation. An ACL injury modifies knee kinematics, increases objective knee laxity, and may induce a subjective knee instability with repetitive giving way episodes, decreased knee function, and the risk to cause secondary lesions of the intra-articular soft tissues like the menisci or the cartilage. Most of the ACL injuries cause an incapacity to participate in pivoting sports like handball. More than 30.000 annual reconstruction procedures are performed in a country of 60 million people like France [1] and about 60.000 in the German-speaking countries. This corresponds to an incidence of approximately 1 ACL injury per 1000 inhabitants. Restricting this incidence to specific groups at risk, i.e., athletes from pivoting sports like handball, football, or basketball, would increase these numbers into the percent-range.

The problem of the high incidence of severe knee injuries in general and ACL injuries in particular occurring in handball has been raised in the late 1990s [2, 3]. The total injury incidence in handball has been reported since to be at 10–40 per 1000 playing hours [3–7]. The rate of severe knee and especially ACL injuries has been estimated to be around 0.2–0.8 in male and 0.7–2.8 per 1000 playing hours in female athletes [2, 3, 8].

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Handball-specific data gained from the Scandinavian ACL reconstruction registries showed that approximately 10–20% of ACL reconstructions are performed in handball players, with a relative increased prevalence in women of two to five times [9–12]. The reasons for this gender discrepancy are mainly of anatomic and biomechanical origin [13, 14]. As all ACL injuries are not treated operatively and hence do not appear in the ACL reconstruction statistics, the true total number of sports-related ACL injuries, and more specifically, handball-related ACL injuries, is not known [15]. It would probably be superior to the abovementioned figures of several 10.000 injuries per year. These numbers reflect nearly epidemic proportions. Given the severity of the injury, as well as its potential impact on an athlete's later life in terms of threatening of the sports career, recurrent operations, and risk for sports-injury induced osteoarthritis, it would be valuable to have specific numbers from sports at risk like handball.

20.2 Injury Mechanism

Approximately 80% of the ACL injuries in handball are noncontact injuries, occurring either with or without perturbation of the player through an opponent or another external cause [8, 16]. A majority of them happen after landing or during sidestep cutting. This injury mechanism is rather characteristic, and knowing it may help for an early diagnosis. In these cases, a valgus trauma occurs, also called valgus collapse. An early analysis explained that the ACL injury was caused by an impingement of the ligament against the lateral femoral condyle which was induced by a combination of a tibial rotation and forced quadriceps contraction. The same Norwegian research group developed their hypothesis further by using video analysis and computerized modeling of the knee [17]. In the two playing situations mentioned above, an important valgus force is applied to the knee at a 20–30° flexion angle. This causes a compression of two convex parts of the joint against each other, i.e., the lateral femoral condyle and the lateral tibial plateau. After initial contact of the two parts of the joint at the impact of the foot on the ground, the spheric lateral femoral condyle slides posteriorly on the lateral tibial plateau, instead of anteriorly in a normal flexion movement. At this moment, approximately 40 ms after landing, the rupture of the ACL occurs. Compression forces of 3.2 times body weight are generated in the lateral knee compartment. During further flexion, the lateral femoral notch impacts against the corner of the posterolateral tibial plateau. This results in a forced internal rotation of the tibia in relation to the femur. The tibia externally rotates shortly thereafter in a reflex movement, in order to get back to a normal position (Fig. 20.1).

20.3 Associated Injuries

Depending on the energy of the trauma (position of the player at landing, speed, weight, etc.), ACL lesions may be partial or complete. Only 30–40% of all ACL injuries are isolated. In most of the cases, several other anatomical structures of the knee can be injured, resulting in combined injuries (i.e., posterior cruciate ligament, medial collateral ligament, lateral collateral ligament, anterolateral ligament or iliotibial tract, posterolateral structures, menisci, cartilage).

20.4 Risk Factors

Many studies have analyzed the extrinsic and intrinsic risk factors for ACL injuries [8, 16, 18–34] (Table 20.1; Fig. 20.2). Increasing evidence appeared over time that the number of severe knee injuries and particularly ACL injuries could be reduced in handball and other pivoting sports through the modification of intrinsic risk factors with primary prevention exercises and an adequate neuromuscular training [6, 8, 35]. The precise origin of this effect has not been identified yet. The current hypothesis is that it is an association of several factors including a counteraction of the dynamic valgus position of the knee through strengthening exercises of the hip abductors [36] or the medial hamstrings [19, 33]. There is also increasing evidence that non-modifiable intrinsic risk factors like a positive family history, physiologic knee laxity, and knee recurvatum

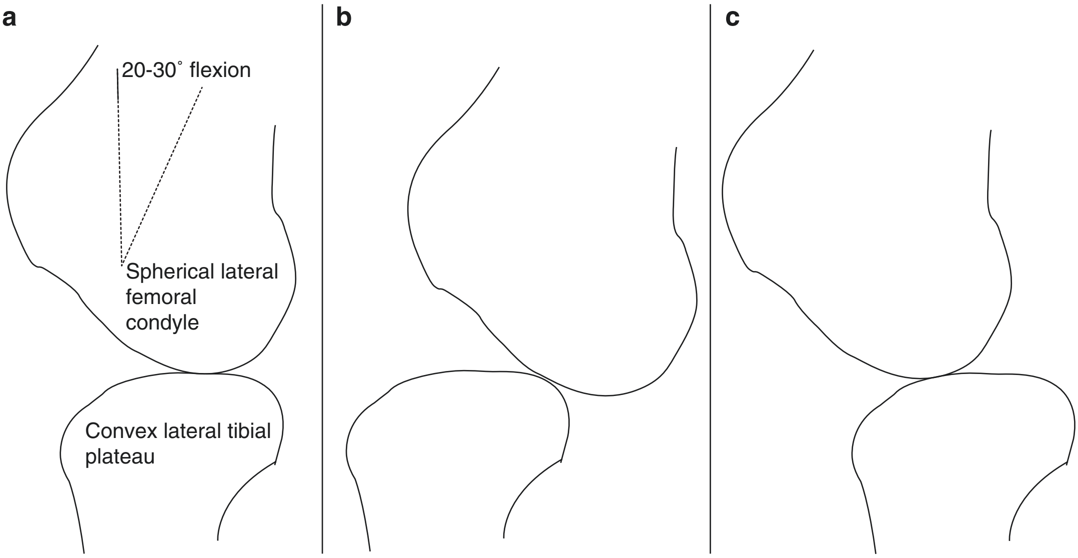

Fig. 20.1 Sagittal view through the lateral compartment of the knee during the valgus collapse, the injury mechanism which is the most frequently responsible for ACL ruptures. The ACL injury occurs about 40 ms after landing when the knee is at about 20° of flexion. At the time of impact of the foot on the ground when there is the initial contact of the joint surfaces (**a**), the spherical femoral condyle slides posteriorly on the convex lateral tibial plateau and leads to the ACL rupture (**b**). This results in a forced internal rotation of the lower leg. During the subsequent reflex-like reduction of the femoral condyles, the external rotation of the lower limb (**c**) occurs. Adapted from [99]

Table 20.1 Potential risk factors for sport injuries

	Modifiable risk factors	Non-modifiable risk factors
Intrinsic risk factors	Fitness level Force Flexibility Joint stability Biomechanical changes Balance/ proprioception Core stability Psychological factors	Age/maturity Gender Previous injury Joint laxity
Extrinsic risk factors	Rules and regulation Coaching education Playing time Playing surface Equipment	Type of sport Weather Level of play Time of season Sport context Playing position

[13, 37], as well as other morphological factors like the tibial slope [38–40], play an important role in the occurrence of noncontact ACL injuries. Unfortunately, the effectiveness of a prospective screening of players at risk is still difficult and controversial [30, 41–43].

With respect to the high amount of secondary ACL injuries which include recurrent ACL tears after reconstruction, as well as ACL injuries of the contralateral knee, secondary prevention of ACL injuries is gaining in importance [44–46]. Recent studies have shown that especially 15–20-year-old female athletes have a risk of approximately 33% to sustain such a second ACL injury. Future research efforts need to concentrate on this serious problem in athletes. If the abovementioned importance of the medial hamstrings in the prevention of the valgus collapse will be confirmed [44–46], the use of hamstring tendon grafts for ACL reconstruction in handball players will need to be reconsidered.

A negative influence of extrinsic risk factors was reported by Olsen et al. in 2003 [47]. They found an increasing number of severe knee injuries in handball on artificial floors in comparison to wooden floors. In how far the artificial floors of that time are comparable to the currently available materials is debatable.

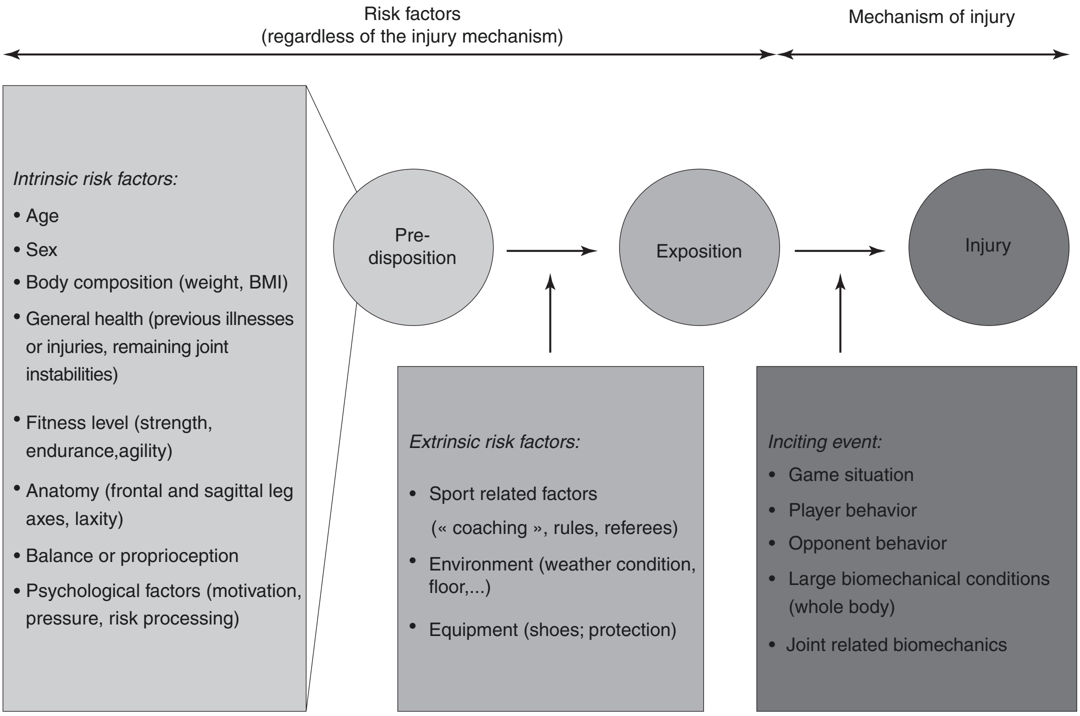

Fig. 20.2 The sports injury model adapted from [100]. The model illustrated the several factors that may influence the occurrence of the injury

20.5 Diagnosis

The valgus collapse is characteristic of a noncontact ACL injury. Observing and understanding this injury mechanism may often help to suspect an ACL tear from the start. In most of the cases, the players are obliged to discontinue the game because of knee pain, swelling, and/or instability. On rare occasions, a dislocated meniscus bucket handle may block the knee and cause an extension deficit. In this acute phase, knee immobilization and application of cold packs or ice, as well as compression, are recommended.

The clinical assessment should always include both knees. After observation of the patient's standing alignment and gait, the examination should start with the noninjured knee, the patient lying supine. It will provide information on the patient's morphotype, the presence of a recurvatum knee or an extension deficit, and the presence or absence of a previous surgery on the contralateral knee. If an ACL injury is suspected in the injured knee, the Lachman and pivot shift tests need to be applied. The latter is often difficult if not impossible to perform in the acute setting. Care should be taken to exclude associated injuries of the posterior cruciate ligament (PCL) and/or the collateral ligaments. The integrity of the PCL is easy to test with the posterior drawer at 90° of knee flexion. A lesion of the medial collateral ligament (MCL) can be ruled out by applying a valgus force to the knee in full extension or at 30° of knee flexion. The lateral collateral ligament can be easily palpated in the figure-of-4 position and its stability tested by applying a varus force. Posterolateral corner injuries can be diagnosed by applying a posterolateral drawer at 90° of knee flexion or with the dial test. For the latter the patient is lying in the prone position, and a side to side difference in external rotation at 30° and or 90° indicates the presence of an injury of the posterolateral structures.

Standard radiographs (anteroposterior, lateral, 45° weight bearing and eventually patellofemoral skyline views) are recommended on a systematic basis. They will provide information on joint space narrowing, the presence of a bony ACL or PCL avulsion, a lateral femoral notch sign, a Segond fracture, and an arcuate avulsion fracture and, in rare cases, will allow to rule out a tibial plateau fracture. A lateral monopodal weight bearing (single leg stance) view of both knees will provide information on the spontaneous anterior drawer of the tibia. It may be completed by stress radiographs, either in the frontal or the sagittal plane by using a TELOS® device.

Although MRI is recommended systematically in ACL-injured patients, it does not replace the clinical examination, which is still the main diagnostic tool. MRI provides information on the integrity of the ACL, and it is at least as important in the diagnosis of associate injuries of the cartilage and menisci, as well as the characteristic bone bruise pattern. A bone bruise of the posterolateral tibial plateau, which is caused by the subluxation of the lateral femoral condyle, is pathognomonic of an ACL injury. Major impaction fractures at this specific location are rare, but they may indicate the need for a surgical reposition during ACL reconstruction in order to prevent a recurrent ACL injury. In that sense, this lesion can be compared to the Hill-Sachs lesion of the shoulder. MRI is also helpful in diagnosing PCL or collateral injuries and in providing information on their topographical location (i.e., femoral vs. tibial avulsion). Devices like the Porto Knee Testing Device® [48] add the possibility to visualize coupled rotation under semi-dynamic conditions and may add value on rotational stability as well as in cases of partial ACL injuries.

ArthroCT scanning may be occasionally required to provide additional information on specific cartilage injuries, fractures, and meniscus lesions.

Laxity measurements with devices like the KT1000®, the GNRB®, or similar are very useful in quantifying pathological laxity as well as to provide additional diagnostic information in those rare cases, where neither the clinical examination nor MRI allow for a secure diagnosis [49].

20.6 Treatment in the Acute Phase

Surgery is rarely indicated in the acute phase. It may be envisaged if a major associated injury is present (i.e., dislocated meniscus bucket handle tear; major chondral or osteochondral flake fracture; multiligament injury). In this case, the surgical treatment of the associated lesion has often priority over the ACL reconstruction. A mistake which should be avoided is to reconstruct the ACL in a setting where the knee is still in an inflammatory phase and where full knee extension has not been achieved preoperatively. This can be caused by a mechanical extension deficit (i.e., dislocated bucket handle of the meniscus or dislocated ACL stump) or by a reflex mechanism of hamstring tightening [50]. Reconstructing the ACL in the inflammatory phase adds additional trauma and tissue insult which may lead to severe arthrofibrosis, permanent extension deficits, need for reoperations, and inability to return to sports. A staged ACL reconstruction procedure after the treatment of the cause of the extension deficit is recommended in these cases. ACL reconstruction can usually be envisaged 4–6 weeks after the injury or the initial surgery. Immobilization is only required in the very early stages after injury for pain control and decrease of the initial inflammatory response to injury. If surgery has been performed for an associated injury, immobilization may be required to protect a reconstructed structure (i.e., after meniscal repair). A thorough rehabilitation program, also called prehabilitation, should be initiated in this setting before envisaging ACL reconstruction. It consists of cryotherapy and medications to decrease the inflammatory process, regaining the full range of motion and muscle activation to regain subjective stability and neuromuscular control of the knee. The current revival of ACL repair in an acute setting, which can be seen in some European countries [51], lacks supporting scientific evidence and cannot be recommended in handball players.

20.7 Indication for ACL Reconstruction Surgery in Handball Players

The goal of an ACL reconstruction is to restore normal knee stability and allow the athlete to regain subjective knee stability. Return to handball without ACL reconstruction has been reported [24], but it cannot be recommended on a systematic basis. Indeed, in the absence of an intact ACL, the risk to have an insufficient neuromuscular control of the injured knee and to sustain repetitive giving way episodes is considered to be too high in a pivoting and contact sport like handball. Although the line of distinction between surgical and nonsurgical management has not clearly been drawn yet [52–56], ACL reconstruction is generally recommended in handball players desiring to return to handball practice. As mentioned previously, ACL reconstruction is rarely an urgent operation. Decision-making should be handled carefully by the athlete and his or her environment. At the time of surgery, the injured knee should be free of pain and swelling, and range of motion should be fully restored. Seasonal timing, the short and long term athletic and professional careers, as well as the risk of second ACL injuries must be taken into account from the start. The problem of very young players with open growth plates is addressed in a separate chapter in this book.

20.8 ACL Reconstruction Surgery

Surgical treatment of ACL injuries has been controversial over several decades. Suture repair has been frequently tempted in the past, but it has resulted in an unacceptably high amount of surgical failures. Extraarticular reconstructions without addressing the intra-articular ligament lesion have also proven to be insufficient. Only reconstructions of the ligament itself have provided satisfactory clinical results on a near systematic basis. In addition, these results are reproducible by a majority of well-trained and experienced knee surgeons.

The principle of the procedure is to replace the torn ligament (Fig. 20.3) by a graft (Fig. 20.4)

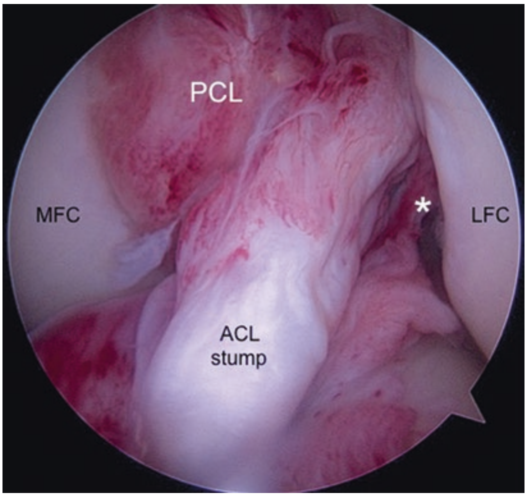

Fig. 20.3 ACL injury by avulsion of the femoral attachment as documented by an empty lateral femoral notch wall sign (*). The ACL stump has healed on the femoral attachment site of the PCL (*LFC* lateral femoral condyle; *MFC* medial femoral condyle; *PCL* femoral attachment of the posterior cruciate ligament)

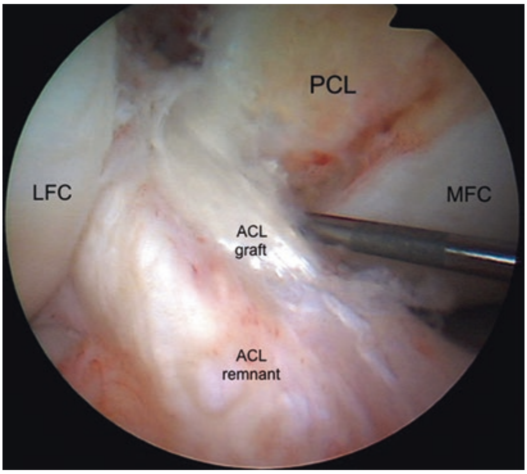

Fig. 20.4 ACL reconstruction in a 30-year-old female handball player with a bone patellar tendon bone graft and preservation of the remnant of the original ACL (*LFC* lateral femoral condyle; *MFC* medial femoral condyle; *PCL* femoral attachment of the posterior cruciate ligament)

which should ideally represent similar anatomical and biomechanical characteristics to the native ACL. Several graft tissues are available. Grafts originating from the patient, also called autografts, should be preferred over donor grafts which are provided by tissue banks (allografts) or artificial grafts. Allografts need twice the time of autografts to be biologically incorporated by the receiver organism [57], which is one of the reasons why they do not appear to be the first choice in handball players. Artificial grafts may allow for an early return to sports practice. For this reason, their choice may be an option in exceptional cases in professional handball players, i.e., if a player sustains an ACL injury shortly before a last important competition at the end of his or her career. In this respect it must be noted that artificial grafts are not a long-term solution. A significant amount of research has been performed on these implants in the 1980s and 1990s. Their use has been abandoned since, because of disappointing clinical results and a high number of complications in the long term.

Autografts are currently the gold standard for ACL reconstruction procedures. Several types of autografts are available for routine use in primary ACL reconstructions. The most popular grafts are the medial hamstring tendons (semitendinosus and gracilis tendon grafts) which can be used either in isolation or in combination; the middle strip of the patellar tendon, which is used with a small bone block from the proximal tibia and the distal patellar pole (bone-patellar tendon-bone grafts) and the quadriceps tendon graft, which is harvested with a bone block from the proximal patellar pole. Minimally invasive harvesting techniques have been described for all of them. The mechanical characteristics of a native ACL decrease with age. In a young adult patient, the ACL has a maximum failure load which is superior to 2000 N and a stiffness approximating 200–250 N/mm [58]. The cited autografts have shown similar biomechanical qualities. On rare occasions, fascia lata tendon autografts are still used by some surgeons. None of the grafts has shown to be superior, and all of them can be recommended in handball players. As mentioned previously, the role of the medial hamstrings in the prevention of the valgus collapse needs to be confirmed [44–46]. Depending on these results, as well as their capacity to regain their specific function after harvesting, the use of hamstring tendon grafts for ACL reconstruction in handball players may need to be reconsidered.

Many individual surgical techniques have been developed and are still under discussion. The current standard is considered to be an intra-articular ACL reconstruction procedure. Minimally invasive arthroscopic surgery has gained overall acceptance, not only for ligament reconstruction but especially also for the reconstruction of the menisci. The basic principles of the procedure are to position the graft anatomically at the insertion sites of the native ACL without creating a conflict with other anatomic structures (i.e., the intercondylar femoral notch) and to fix it in the chosen position. Anatomic graft positioning is done arthroscopically by using specially designed guides to drill bony tunnels at the original insertion sites of the native ACL. A large variation of surgical techniques has been described for tunnel placement. They can be drilled in an outside-in fashion or vice versa. Their diameter varies with the size of the patient, with the most usual diameters being 8 or 9 mm. Graft fixation techniques vary widely and depend mainly on the type of graft. There are either direct fixation techniques with interference screws or indirect, suspensory techniques. The graft can be implanted as a single bundle or with two bundles. The latter technique requires drilling of four tunnels instead of two and is much more complex than the single-bundle technique. It became popular in the early 2000s and is still frequently used in some countries like Japan. Its primary advantage over a single-bundle technique was to offer a better rotational control of the knee, but this could not be proven definitively. In addition, the last years have shown other important factors appearing to be important for rotational control of the knee, which is one of the reasons why double-bundle ACL reconstruction techniques have never been adopted or are currently being abandoned in Europe and North America by a majority of surgeons. In experienced hands, an ACL reconstruction technique lasts approximately 30–60 min. Depending on the organization of the local healthcare system, ACL reconstructions require a short hospital stay of 1–3 days, or they are performed on an outpatient basis.

20.9 Surgical Treatment of Associated Injuries

The most frequent associated injuries are meniscus and cartilage lesions. Although the role of the menisci as secondary stabilizers has been well established for decades, meniscus lesions were neglected or were treated with meniscectomies for many years. Over the last two decades, meniscal repair techniques have been significantly improved, and nowadays the importance of meniscus preservation in association with ACL reconstruction is well established. Healing of meniscal repair can be expected in 80–100% of the cases. Patients undergoing total meniscectomy are at two- to tenfold increased risk of developing osteoarthritis in comparison with those with intact menisci [59]. It has been well established that meniscal deficiency is the most significant factor to predict ACL graft failure, which seems to be more important than nonanatomic femoral tunnel positioning and younger patient age [60].

Furthermore, in recent years several specific associated meniscus injuries have been described, and recent investigations have identified new and more precise aspects of their stabilizing function. On the medial side, meniscal ramp lesions (Fig. 20.5) have been observed in 15–25% of ACL injuries. The reason why they have been missed in the past although their first description dates back to the 1980s [61] is that their diagnosis is difficult. They can hardly be recognized on MRI, and they cannot be seen through standard anterior arthroscopy of the medial compartment. They can often be only properly identified through an arthroscopic inspection of the posterior part of the knee and an additional posteromedial arthroscopic approach [62, 63]. Because of their biomechanical impact, repair of these lesions is recommended [64]. The second type of meniscus injuries which deserve more attention is the posterior root tears of the lateral meniscus (PRLM) (Fig. 20.6). They are present in approximately

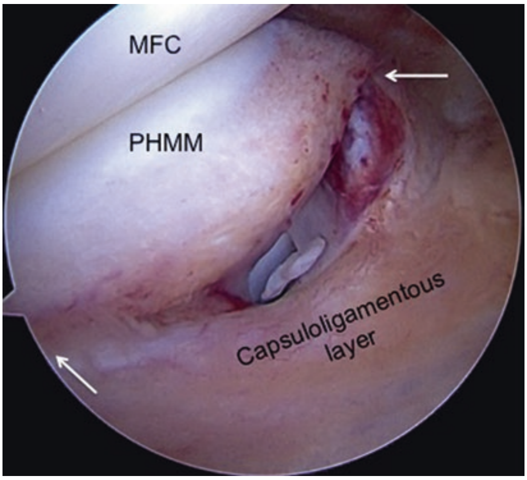

Fig. 20.5 Ramp lesion of the medial meniscus observed through a posteromedial arthroscopic portal (*MFC* medial femoral condyle; *PHMM* posterior horn of the medial meniscus). The arrows delimitate the ramp lesion extending from the intercondylar notch region (right) to the insertion of the medial collateral ligament (left)

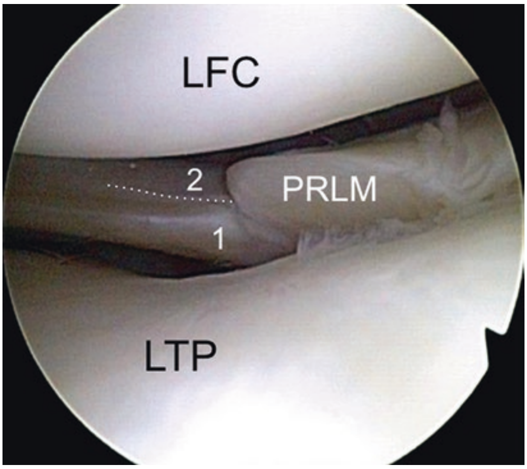

Fig. 20.6 Posterior root tear of the lateral meniscus (PRLM). The subluxation of the lateral femoral condyle (LFC) behind the lateral tibial plateau (LTP) causes a disruption of the meniscal attachment to the tibia, leaving a stump of the meniscotibial attachment as well as an incomplete tear (dotted line) of the remaining posterior horn. The latter is separated into two portions: the anterior is the former meniscotibial attachment (1), and the posterior (2) is prolonged into the meniscofemoral attachment (Humphrey ligament)

15% of ACL injuries. Sectioning the posterolateral root leads to an increase in internal rotation of the knee [65]. PRLM do rarely jeopardize the stability of the meniscus but may contribute to the severity of the pivot shift phenomenon also clinically detectable. Therefore, repair of these lesions is recommended whenever possible. The techniques for the repair of these two lesional types as well as the clinical results are under investigation.

In some cases, an ACL injury is combined with an injury of the peripheral structures like the anterolateral capsule, the anterolateral ligament (ALL) [66] (which causes the Segond fracture and which is a pathognomonic sign of an ACL injury), or the iliotibial band with its Kaplan fibers. These patients do often present a high-grade rotatory laxity (grade 3 pivot shift) and may need an additional lateral extraarticular tenodesis [67]. Indeed, it has been shown that rotational control may not be sufficiently restored after isolated ACL reconstruction, even if the ACL graft has been placed in an anatomically correct position. It is commonly admitted that insufficient rotatory control leads to a higher incidence of recurrent ACL tears [68]. As it is very difficult to define which part of rotational laxity originates from intra-articular lesions like meniscus injuries, which part is caused by peripheral damage, and which may be the best surgical solutions to address rotatory laxity, the topic of remaining rotational laxity after ACL reconstruction is controversially discussed in the current scientific literature [69]. For the defenders of lateral extraarticular procedures, the usual indications for combination of intra- and extraarticular procedure are currently high-grade rotation laxity (pivot shift grade 3), high-demanding and contact athletes, generalized ligamentous laxity, and ACL revision. There is still no evidence about exact and accurate indications for the lateral procedures (ALL reconstruction or lateral tenodesis). However, in the setting of a highly demanding and pivoting sport like handball, meaning higher risk of graft stretch and re-rupture, one should consider the utility of the lateral extraarticular procedure in some selected cases [70, 71].

Males have an increased risk of full-thickness cartilage lesions compared with females, and male handball players have an increased risk compared with male athletes from other sports [72]. The reasons for this recent finding are not clear. It may be related to morphological factors of handball players, their level of play, or the amount of energy transferred to the knee at the moment of injury. It is rare that surgical cartilage procedures are required in association with ACL reconstruction. In young players, a chondral flake fracture may need fixation. In case of grade 4 cartilage lesions, microfracturing can be recommended. In exceptional cases of small osteochondral lesions, osteochondral autografting may be required.

20.10 Rehabilitation of ACL Injuries

After an ACL injury, priority must be given to reduce pain and swelling, to regain normal knee motion, and to restore active knee stability. This process is highly variable between patients and usually takes between 4 and 6 weeks. Important principles are quadriceps stimulation and hamstring co-contractions, early active rehabilitation (2–3 weeks after surgery), and avoidance of early heavy open kinetic chain exercises. Rehabilitation after ACL reconstruction in handball players consists of several phases. The early postoperative phase is comparable to the post-injury phase, with the main goals being control of pain and swelling as well as regaining range of motion (ROM). In case of associated meniscal repair, a limitation of ROM is usually imposed by the surgeon. Most surgeons block the knee in extension with a brace, allow for full weight bearing, and limit ROM to 0–0-90° for 6 weeks. Deep squatting should be avoided for 3–4 months. Non-weight bearing is usually instructed for 6 weeks if a meniscal root fixation has been performed. In case of an isolated ACL reconstruction, these restrictions do not need to be instructed/perscribed.

Over the last years, the rehabilitation process that follows this early period has evolved from time-based to criteria-based rehabilitation principles. This will be addressed in detail in a separate chapter in this book. Roughly, athletes with isolated ACL reconstructions can envisage to resume with running approximately 3 months postoperatively. After 4 months, they can consider starting on-field rehabilitation and after 5 months, on-field sport-specific rehabilitation. If they comply with the functional criteria, athletes should be ready for team training at 6–9 months. Before resuming competition, a team training of at least 3–4 weeks should have been accomplished after successful functional evaluation.

The long rehabilitation process needs to be interdisciplinary and should ideally bridge the gaps between surgeons, physiotherapists, and coaches in order to allow a safe return to handball practice. Forcing return to sports (RTS) puts the athlete at risk to sustain either a recurrent or a contralateral ACL injury [73]. Indeed, the risk of a reinjury has been shown to be as high as 33% in young athletes under the age of 20 [74]. Before RTS can be envisaged, systematic functional testing is recommended. If a limb symmetry index of >90% across a battery of tests is reached by the player, RTS can generally be envisaged. In terms of timing, a period of at least 6–9 months must be considered, knowing that each month of additional rehabilitation before RTS decreases the reinjury risk [73].

20.11 Complications

Arthroscopic ACL reconstructions are commonly performed procedures, but they are technically challenging, involving multiple surgical steps. Although they are rare in experienced surgeons' hands, they bear the potential of a wide range of surgical complications [75]. In case of persisting or recurrent pain, swelling, or limited ROM, a new diagnostic assessment with plain radiographs and MRI is recommended. Graft malpositioning may lead to early failures and limitations in ROM. In case of a persisting extension deficit, the development of a cyclops syndrome needs to be excluded. Flexion deficits are often the result of a two anterior femoral graft positioning. Chronic pain may have several origins. Pain located at the patellofemoral joint may be the result of patellar tendinitis with or without relation with previous graft harvesting [76]. Insufficient muscle force may be another cause of pain, occurring at or after a physical effort. In some cases, posttraumatic meniscus or cartilage injuries may become symptomatic. If no specific structural cause may explain the symptoms, chronic regional pain syndrome should be considered.

20.12 Outcomes after ACL Reconstruction

Although a majority of patients will be able to resume participation in handball, a successful return to sport after ACL reconstruction cannot be guaranteed. A recent systematic review from different sports showed that only two-thirds of athletes managed to return to competitive sports, which is lower than expected [77, 78]. However, in general, return to sport rate is higher among elite-level athletes reflected by an overall 83% (95% CI: 77%–88%) return rate [79] and as high as 97% in elite-level football [80]. After revision ACL reconstruction, approximately 53% of patients have been reported to return to preinjury sport [81].

Criteria for return to sports are poorly investigated and described. The most commonly used criteria described in the scientific literature are time from ACL reconstruction, knee range of motion, functional tests (such as different hop tests), balance, and isokinetic strength tests of the knee extension and knee flexion reflecting quadriceps and hamstrings muscle strength [82]. It is recommended that the injured leg should regain 90–100% of the strength of the non-injured side before returning to sport-specific training and pivoting contact participation in sport [73, 83–85]. These strength recommendations are based on between-leg comparisons, usually reported as a limb symmetry index (LSI), and are a good reference to guide postoperative treatment for clinicians. Unfortunately, there is no normative data available on the absolute strength requirements for handball or other sports [85]. Recovering a symmetrical function, strength, and hop performance can be challenging and take a prolonged period of time. A reduced quadriceps and hamstrings strength can persist 1–2 years after ACL reconstruction in a general population [86–88], and remarkably less than 10% of patients are able to achieve a symmetrical performance, an LSI >90%, across a battery of strength and hop tests 1 year after surgery [89]. Achieving an LSI >90% in several tests of muscle function should be considered as a minimal criteria before a return to handball in regard to the association with a large reduction of secondary injuries among patients who achieve these criteria [73, 90]. It has been shown that athletes who don't meet the discharge criteria (like isokinetic strength testing at 60°, 180°, and 300°/s, a running *t* test, single hop, triple hop, and triple crossover hop tests) before returning to professional sport can have a four times greater risk of sustaining an ACL graft rupture compared with those who meet all [90]. In terms of high-level handball players, those who have sustained an ACL injury can achieve a similar strength and balance compared with uninjured players 1–6 years after reconstruction. However, a persistent quadriceps strength reduction of 6.3%, and a 17% greater knee joint laxity, has been reported in the injured leg compared with the uninjured leg in handball players who have sustained an ACL injury [91]. Handball players who sustain an ACL injury may, therefore, in particular benefit of a continued specific strength program as secondary prevention even after 1 year postsurgery. Patient-reported psychological outcome should also be a part of the RTS evaluation after ACL injury, in particular for the high-level athlete since deficits have been documented [92]. For instance, subjective perception of knee function among ACL-injured handball players is strongly affected by injury history, with clinically relevant lower scores for the subjective knee function including pain, function, sport, and quality of life (based on the knee injury and osteoarthritis outcome score) [91]. In general, achieving a score of at least 85% in a patient-reported outcome has been suggested as a guideline for return to sport [93].

Most of the data existing on the outcome of ACL reconstructions in handball players have been extracted from the Scandinavian ACL reconstruction registries. They show that the results of ACL reconstruction do not differ between handball players and athletes from other pivoting sports. ACL reconstruction studies report a dramatically high risk of sustaining a second ACL injury with up to 18% of recurrent tears in athletes under the age of 20 [74] and 5.2% (2.8–8.3%) among elite-level athletes [79], where most of the failures occur in the first 2 years after surgery. In players under the age of 20 have, roughly one out of three to four athletes experience a recurrent tear on the operated side or an injury on the contralateral side. The reasons for this are not clear and are currently under investigation. The increased risk of sustaining an additional ACL injury among young players is important to consider since the proportion of pediatric and adolescent patients who return to high-risk sports has been reported to be between 69 and 92% [94–97]. These results show that RTS in young players under the age of 20 needs to be considered with great care, especially in female athletes who are at higher risk for reinjury. In addition, fear of a new injury is one of the primary reasons for never returning to or dropping out of sport in young athletes after ACL injury [98]. No specific handball data exist with respect to RTS rates after ACL reconstruction.

Conclusion

ACL injuries in handball are a serious problem. They are too frequent and do not only represent career-threatening injuries in the short term but also a potential cause of osteoarthritis in the long term. Due to the repetitive pivoting movements in handball, ACL reconstruction is highly recommended in case of desire to resume handball practice. Management of ACL tears starts right after the injury with a thorough rehabilitation program. In some cases, early surgery may be required. In most of the patients, surgery must be considered after the end of the inflammatory phase, in a pain-free knee with full range of motion. Many types of surgical techniques are currently available. Arthroscopic intra-articular ACL reconstruction with autologous tendon grafts is the first choice of treatment. In patients with big knee laxities, additional extraarticular stabilization may be required. Lateral meniscal tears may be more prevalent in handball in concomitance with an ACL injury compared to other sports. Meniscus preservation is important for optimal knee function and for the prevention of osteoarthritis in the long term. Although most of the players will be able to return to sports (RTS) after ACL reconstruction, this cannot be guaranteed. RTS can generally be considered after a thorough rehabilitation period of 6–9 months. Whereas in elite-level athletes failures of the ACL reconstruction are generally inferior to 5%, one out of three to four young players under the age of 20 suffer from a secondary ACL injury of the contralateral knee or a graft tear in the operated knee. RTS should be preceded by functional assessments, including strength measurements and hop tests. The development of interdisciplinary strategies to bridge the frequent gap between physiotherapy and return to competition is highly recommended to allow for a safe RTS practice.

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21

Management of PCL Injuries in Handball

Markus Waldén and Lior Laver

21.1 Anatomy and Function

The posterior cruciate ligament (PCL) is one of the four major stabilising ligaments of the knee joint in conjunction with the anterior cruciate ligament (ACL), the medial collateral ligament (MCL) and the lateral collateral ligament (LCL).

21.1.1 Anatomy

The PCL is named after its attachment in a sulcus on the posterior tibia approximately 1 cm below the tibial surface and is an intra-articular, but extrasynovial, ligament just as the ACL (Fig. 21.1) [1–3]. Anteriorly, the PCL attaches in the femoral notch on the medial femoral condyle, and most studies have identified two principal portions or bundles of the PCL [1–5]. The fibres in the larger anterolateral bundle, which is the bulk of the ligament, are taut in flexion and lax in extension, whereas the reverse is seen for the fibres in the thinner posteromedial (oblique) bundle. Classically, they were believed to function independently, but this has been questioned due to recent findings of a more synergistic and codominant relationship between the bundles [4].

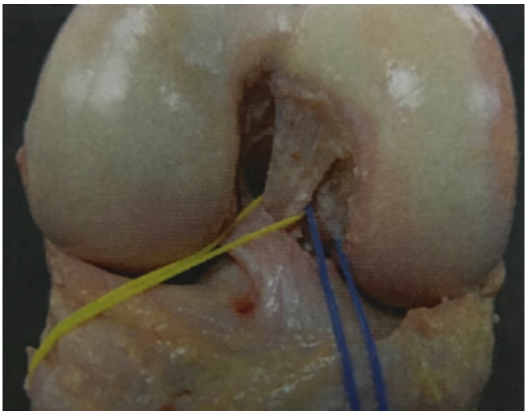

Fig. 21.1 Anatomy of the PCL showing the anterolateral bundle (marked in yellow) and the posteromedial bundle (marked in blue)

Two menisco-femoral ligaments, present in most individuals, are anatomically related to the PCL. The ligament of Humphrey is located anterior to the PCL, and the ligament of Wrisberg is

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located posterior. These ligaments originate from the posterior horn of the lateral meniscus, bifurcate around the PCL and insert anterior and posterior to the PCL on the medial femoral condyle [6, 7].

21.1.2 Function

The PCL provides more than 90% of the total restraint to posterior displacement of the tibia on the femur [2, 3, 5]. Maximal tension of the PCL is seen at full flexion, and sectioning of the ligament results in an excessive posterior translation in flexion but very minimal at full extension [1, 2]. More recently, the PCL has also been identified as a secondary restraint to rotation, and complete sectioning also results in an increase in internal rotation beyond 90° of flexion [4].

In contrast to several cadaveric studies, no clinical studies have demonstrated significant varus–valgus instability with PCL deficiency. Gait analysis studies failed to demonstrate any significant differences between PCL-deficient and normal limbs in terms of varus–valgus instability [8–10].

The posterolateral corner (PLC) structures, which consist of the lateral collateral ligament (LCL), the popliteofibular ligament and the popliteus tendon, have an important synergistic relationship with the PCL to control posterior translation and external rotation [11]. Biomechanical studies have shown that only the combined section of both PCL and PLC results in functionally significant laxity compared with an isolated section of either structure alone [1]. This means that severe posterior laxity on clinical examination should raise suspicions of a combined PLC lesion.

21.2 Injury Epidemiology

PCL injuries are in most of cases (approximately 90%) the result of a traffic accident or trauma during sports activities [12, 13]. However, PCL injuries are quite rare injuries in sports compared with other acute knee ligament injuries such as MCL and ACL injuries [13, 14]. The incidence in the general population is also low, 1.8 per 100,000, as recently shown for total tears of the PCL confirmed with MRI [15].

Fact Box

Isolated or combined PCL injuries are rare both in a general and athletic population. Most of PCL injuries occur in traffic accidents or in sports-related activities.

21.2.1 Handball

Most sports-related PCL injuries are reported to occur in football [12, 13], and proper numbers in handball are essentially lacking. However, handball was the fourth most common specific activity after traffic accidents/motorsports, skiing disciplines and football in a recent study on 1287 PCL reconstructions from the Scandinavian Knee Ligament Registries [12]. A total of 80 handball players (6.2%) who underwent PCL reconstruction were identified from these registries. Moreover, in a 10-year review of all sports injuries treated at one clinic, there were 51 PCL injuries among 3482 internal knee traumas (1.5%) [14]. Since the percentage of PCL injuries in handball was 2.6% (6 out of 231 handball-related internal knee traumas), the authors concluded that handball players appear to be more susceptible to PCL injury compared with sports such as football (0.5%) and skiing (1.5%). This was recently supported by findings from a registry study that reviewed sport-specific injuries from two ACL reconstruction registries from the United States and Norway from 2004 to 2011 [16]. All 1548 handball players in the cohort (1295 females, 253 males) came from the Norwegian registry. They identified 12 PCL injuries (0.8%) and 55 additional injuries categorised as multi-ligament injuries, where the injured ligaments other than the ACL were not mentioned. The age- and sex-matched odds of sustaining a PCL injury in handball was more than twofold higher than in football. Finally, there were six PCL injuries in a prospective study on 3392 handball players in the three upper divisions for men and women in Norway during the 1989–1990 and 1990–1991 seasons which gives an incidence of approximately 0.06 PCL injuries per 1000 player-hours [17].

21.3 Risk Factors and Injury Mechanisms

Little is known about potential risk factors for PCL injury in sports including handball. However, knowledge on the general PCL injury mechanisms is important and may aid in identifying such injuries despite the lack of more systematic and sport-specific studies in this field.

21.3.1 Risk Factors

In a recent population-based study from the United States, there was an apparent sex discrepancy with more than twice as many PCL injuries identified among males than in females [15]. This male preponderance with approximately a doubled risk in males was also shown recently in the study on PCL reconstructions from the Scandinavian Knee Ligament Registries [12]. This pattern therefore seems to contrast the one identified for ACL injuries where female athletes participating in jumping, cutting and pivoting sports have a well-documented higher risk of ACL injury compared with males [17–20]. However, the literature on potential risk factors for PCL injury is scarce compared with that for ACL injury where extensive, but essentially inconclusive, research is published on anatomical (e.g. femoral notch size, joint laxity, familiar predisposition, etc.), developmental/hormonal (e.g. female sex, maturation status, menstrual status, etc.) and biomechanical/neuromuscular factors (e.g. knee abduction, hamstring recruitment, etc.) [21]. Moreover, the strongest risk factor for subsequent ACL injury, also in the contralateral knee, appears to be a previous ACL injury [22], but this is unclear when it comes to PCL injuries.

21.3.2 Injury Mechanisms

There are three classic injury mechanisms for a PCL injury described in the literature: (1) hyperextension, (2) hyperflexion and (3) pretibial contact with a flexed knee [2, 13]. The latter mechanism could be the typical motor vehicle dashboard injury in which the impact of the crash forces the driver's or the passenger's knee against the dashboard moving the tibia posteriorly in a flexed knee [1, 13]. Alternatively, a fall on the knee with a plantarflexed foot delivers the blow to the tibial tubercle, thus driving the tibia posteriorly injuring the PCL, whereas with a dorsiflexed foot, it is usually delivered more to the patellofemoral joint, thus protecting the PCL [1].

The underlying biomechanical risk profile and the mechanisms for ACL injuries in handball are well described via systematic video analysis studies [23–26], but there are no similar studies on the mechanisms for PCL injuries. In our clinical experience, however, the most frequent PCL injury mechanism in handball is a fall on a flexed knee with contact between the tibial tubercle and the floor driving the tibia posteriorly (Video 21.1). Moreover, in many cases the fall is preceded by player-to-player contact where the injured player is pushed in the back which leads to a forward movement of the trunk and an uncontrolled landing with pretibial rather than patellofemoral impact. In our experience, although a less common one, hyperextension is also a possible mechanism for PCL injury in handball, most commonly forced by contact.

21.4 Diagnostics

Historically, PCL injuries have frequently been under- or misdiagnosed in the acute setting despite typical history, injury mechanism and clinical findings [13]. Except for diagnosing the PCL injury per se, it is paramount in the acute phase to distinguish if the lesion is isolated or combined with other lesions such as the LCL and/or the PLC. Combined injuries are seen relatively more often with vehicular trauma than injuries sustained during sports [13]. It also seems that associated meniscus injuries, especially lateral ones, are not as frequent as for ACL injuries [12, 15].

21.4.1 Clinical Examination

Knee evaluation should begin by obtaining a detailed history of the injury and attempting to delineate the injury mechanism. An isolated sports-related PCL injury is rarely associated with the dramatic picture commonly seen for acute ACL injuries such as the presence of a “pop sign”, early intra-articular swelling and inability to continue with the sport after the incident. In contrast, the PCL-injured athlete can sometimes continue with sport activity and thereafter present with a limp, mild swelling, pain in the popliteal fossa and loss of knee flexion [3, 4].

There are several tests described for assessing the integrity of the PCL, with the most frequently used being the posterior drawer test, the posterior sag test and the quadriceps active test [1, 4, 5].

21.4.1.1 The Posterior Drawer Test

The posterior drawer test is considered the most sensitive of these tests and is performed with the patient supine and the hip flexed to 45° and the knee to 90° (Fig. 21.2). The examiner is sitting on the examination table in front of the involved knee and grasping the tibia just below the joint line. The thumbs are placed along the joint line on either side of the patellar tendon. The tibia is then moved posteriorly, and an increased posterior tibial translation and/ or lack of a firm endpoint indicate either a partial or a complete tear of the PCL. In this respect, it is important to recognise that the resting tibia normally is positioned approximately 10 mm anterior to the medial femur and that a posteriorly directed force in a normal knee reduces this to 0–2 mm anterior to the medial femoral condyle, but never posterior [5]. Traditionally, isolated PCL injuries have been classified into three severity grades based on the manual posterior tibial translation relative to the femoral condyle (Table 21.1) [27]. With a grade I injury, the tibial plateau remains anterior to the condyle, maintaining an anterior step-off (<6 mm translation). A grade II injury is likely when the anterior border of the tibia sits flush with the femoral condyle (6–10 mm translation). With a grade III injury, the anterior border of the tibial plateau translates posterior to the femoral condyle (>10 mm of translation), most likely indicating a complete tear, and associated posterolateral structure damage should also be suspected. It is important to note that the posterior drawer test can be falsely negative or equivocal [28], and the grading in mm of laxity should therefore probably be used with some caution. Failure to use a proper starting position may elicit a false-negative posterior drawer and a false-positive anterior drawer test leading to an incorrect diagnosis.

Fig. 21.2 The posterior drawer test. Photo: UEFA via Getty Images with permission

Table 21.1 Grading of PCL injuries

Grade	Position of resting tibia relative to the medial femur	Posterior tibial translation relative to the healthy knee
I	Anterior	≤5 mm
II	Flush	6–10 mm
III	Posterior	≥11 mm

21.4.1.2 The Posterior Sag Test

The posterior sag test, also known as the “step off sign”, is a static test where the patient is lying supine with the hip flexed to 45° and the knee to 90° similar to the starting position for the posterior drawer test. The examiner views the knees from the side and evaluates any asymmetry in the resting anatomical positions of the tibia (Fig. 21.3). The test is positive if the proximal tibia is found to “sag” posteriorly. The sagging can sometimes be attenuated by raising the hips from 45° to 90°, and this manoeuvre is called the Godfrey test.

21.4.1.3 The Quadriceps Active Test

The quadriceps active test is a dynamic test which preferably can be done immediately after the

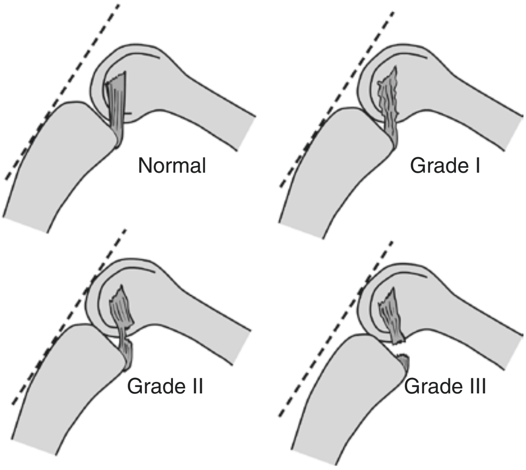

Fig. 21.3 The posterior sag test

posterior sag test using this posture as the starting position with the leg in neutral rotation. The examiner asks the patient to contract his quadriceps muscle or alternatively to attempt to slide the foot anteriorly (to induce a quadriceps contraction), while the examiner is resisting by applying counterpressure against the ankle. The test is positive if a "sagged" tibia moves in an anterior direction to a reduced position.

21.4.1.4 Additional Tests

It is always also mandatory to routinely add tests for any additional injuries to the posteromedial or posterolateral corners such as the posterior drawer test with the foot in internal and external rotation, the dial test and the reverse pivot shift test [1, 4, 5].

21.4.2 Imaging

Plain radiographs still have a role in detecting bony avulsions of the PCL or other skeletal findings of associated injuries. Stress radiographs is also increasingly advocated by some centres in adjunct to plain radiographs because of their ability to provide a reproducible objective assessment of the degree of posterior tibial translation where >8 mm implies a grade III injury [3, 4]. Magnetic resonance imaging (MRI) is nowadays, however, the preferred imaging technique [3, 4], where the normal PCL is curvilinear and appears dark both on T1- and T2-weighted scans (Fig. 21.4). MRI has been proven to be very accurate for acute PCL injuries with reported sensitivity values close to 100% using knee arthroscopy as the golden standard. MRI signs of PCL injury are often most easily detected on T2-weighted images where there is a high signal traversing the fibres partially or completely. However, MRI can be false negative in chronic PCL injuries, especially for partial lesions (grade I and II), where the ligament can appear to have healed in spite of clinical PCL insufficiency [3, 29]. MRI also enables to assess for associated knee injuries such as meniscal injuries, other ligamentous injuries and PLC integrity but can also give insight to the injury mechanism such as a typical medial bone bruising which makes us consider a combined PCL-PLC injury [30].

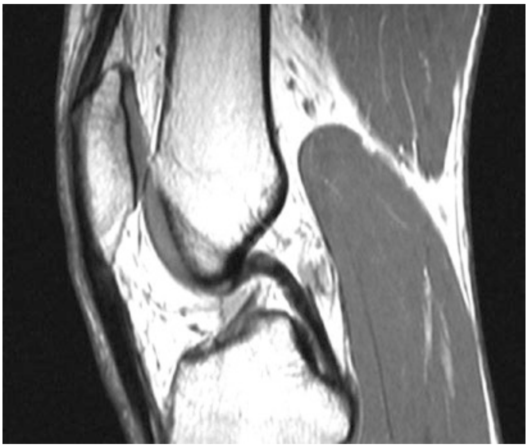

Fig. 21.4 Normal PCL on MRI

21.5 Healing Potential and Treatment

A branch from the popliteal artery, the middle genicular artery, provides most of the blood supply to the PCL which appears to be more abundant than to the ACL [1]. Together with better synovial coverage, this might explain why a number of PCL injuries, especially low-grade lesions, show some radiological healing signs over time with improved fibre continuity and more normal ligament morphology [1, 4, 31]. In addition, the clinical grading can sometimes be improved over time giving further and indirect support that some kind of healing in the PCL might occur [32]. It has also been suggested that the menisco-femoral ligaments may contribute to the healing potential, acting as a splint to keep torn PCL fibres in position while it heals.

The basis to devise the optimal treatment options lies in an understanding of the natural history of the injury. In a clinical series of 45 patients, the natural history of isolated PCL injury was described as occurring in three phases: (1) functional adaptation lasting 3–18 months, with return to sport; (2) functional tolerance lasting for 15–20 years; and (3) osteoarthritic deterioration (medial tibiofemoral or generalised) that does not become disabling until 25 years post-injury [33].

21.5.1 Non-Surgical Treatment

A non-surgical treatment approach for isolated partial (grade I and II) tears is essentially uncontroversial in the literature [3, 5]. Moreover, although this is slightly more controversial, most practitioners also recommend non-surgical treatment initially for isolated complete (grade III) tears [3].

Historically, immobilisation in a cast or in a hinged brace locked in full extension for 2–4 weeks was common to treat PCL injuries, but nowadays there are a few functional PCL-specific braces commercially available [34]. The first clinically validated PCL-specific dynamic brace was the PCL-Jack brace [35], which provides a spring-loaded anterior force to the tibia in order to counteract gravity and the effect of the hamstring muscle tonus in the sitting or supine positions. It is intended to be prescribed within the first 2–3 weeks after injury and should be used 24/7 for at least 12 (up to 16) weeks except when showering and changing clothes (the patient must, however, carefully be instructed to actively translate the tibia anteriorly by contracting the quadriceps in full extension when the brace is not worn). The PCL-Jack brace provides the tibia with a constant anterior force which can be manually set in 15 levels (level 12 which means 6–7 kg is usually standard if tolerated by the patient) but restricts range of motion to approximately 90–100° of flexion and can therefore only be used during the rehabilitation phase [34]. More recently, several new dynamic PCL braces have been introduced as an alternative to the PCL-Jack brace, such as the Rebound PCL and the M.4s PCL braces (Fig. 21.5). These newer braces are less bulky and provide an increasing anterior force with higher knee flexion angles [36] but have not yet been evaluated for use in a return-to-play (RTP) release situation.

Fig. 21.5 Examples of dynamic PCL braces: (**a**) PCL-Jack, (**b**) M4.s, (**c**) Rebound PCL

There are a few detailed rehabilitation protocols after PCL reconstruction [4, 5], but the literature on different rehabilitation steps and exercise progressions is scarce for non-surgical treatment protocols [37]. A recent review on rehabilitation programmes after PCL injury described detailed protocols with stepwise progression for both non-surgical and surgical treatment [37]. A slightly modified and accelerated protocol allowing for return to play (RTP) after 4 months is outlined in Table 21.2. There are no studies reporting specifically on non-surgical treatment in handball players, but a non-surgical approach as described here is in our own clinical experience successful, at least in the short-term, in most cases of handball-related isolated PCL injuries.

21.5.2 Surgical Treatment

Current accepted indications for surgical treatment of PCL injuries are multi-ligament injuries involving the PCL, displaced larger bony avulsions from the tibia and symptomatic (instability) isolated total tears despite a proper neuromuscular rehabilitation programme [3]. Occasionally, a PCL repair is possible, but most often a PCL

Table 21.2 Non-surgical rehabilitation protocol for isolated PCL injuries[a]

Phase	Weeks after injury	Protocol
I	0–6	Prevent posterior tibial translation by using a dynamic PCL-specific knee brace all day Avoid hyperextension and isolated hamstring exercises Full weight-bearing as tolerated (only crutches for a short period if needed) Prone passive range of motion from 0° to 90° for the first 2 weeks and then progress to full flexion Quadriceps activation including straight leg raises (no lag tendency allowed) Stationary biking without resistance Free training of trunk and contralateral limb
II	7–12	Prevent posterior tibial translation by using a dynamic PCL-specific knee brace all day Continued avoidance of hyperextension and isolated hamstring exercises Continued full weight-bearing Full active and passive range of motion Quadriceps activation including double-limb strengthening exercises such as leg press up to 70° Introduce hamstring bridges on ball with extended knees Stationary biking with progressive resistance Continued free training of trunk and contralateral limb
III	13–14	Discontinue use of the dynamic PCL-specific knee brace Full range of motion including hyperextension Introduce running (start by short interval jogging and then progress to high-speed running) Double-limb strengthening exercises such as deep leg press and then progress to single-limb leg press Introduce isolated hamstring exercises such as single-limb bridges Introduce sport-specific agility exercises Continued stationary biking with progressive resistance Continued free training of trunk and contralateral limb
IV	15–16	Continued full range of motion including hyperextension Free quadriceps and hamstring exercises in full range of motion Introduce sport-specific agility exercises and then progress to non-contact return to play Continued free training of trunk and contralateral limb
V	17 +	Return to play including full player-contact allowed if: – Full active range of motion – >90% of the contralateral quadriceps and hamstring strength – >90% of the contralateral limb results in the running and hop test discharge test battery – No subjective instability or giving way – Athlete mentally ready to return to play without fear of reinjury

[a] Modified and accelerated protocol from Pierce et al. [37]

reconstruction is required if surgery is indicated [12]. There is, however, no consensus with regard to surgical approach (e.g. transtibial or tibial inlay reconstruction), graft choice (e.g. autograft or allograft) [4, 5, 12], autograft type (e.g. patella tendon or hamstring tendon) [4, 5, 12] or reconstruction technique (e.g. single-bundle or double-bundle reconstruction) [38], and it is beyond the scope of this chapter to review this in detail. Although subjective and objective measures usually are improved after PCL reconstruction [4], perhaps just as much as following ACL reconstruction in the short term [39].

The rehabilitation protocol after PCL reconstruction essentially follows the same principles as for non-surgical treatment, but there is agreement that each step in the rehabilitation should be longer with delayed introduction of weight-bearing, range of motion exercises and strength training [5]. Several aspects should be emphasised, however, following surgery. Rehabilitation may and should start on the first postoperative day. Physical therapy emphasises early quadriceps muscle activation. Prone knee flexion from 0° to 90°, at least for the initial 2 weeks postoperatively but even beyond that, is a good strategy to avoid hamstring activation which places increased stress on the graft. Weight-bearing exercises and low-resistance stationary bike (maximum of 70° of knee flexion) are usually started at 6 weeks. Progressive evolution into low-impact knee exercises is allowed as tolerated by the patient, starting 12 weeks after the surgery. Six months postoperatively is a good time for a thorough clinical assessment, and kneeling posterior stress radiographs could be added to as an objective reference [40].

21.6 Return to Play

Fact Box

It is paramount to distinguish if the PCL injury is isolated or combined.

The most frequently used clinical test to verify a PCL injury is the posterior drawer test.

The responsible physician and other medical practitioners involved always need to be prepared for the "when can I play again?" question from the injured player [41]. Ideally, a safe RTP with a low subsequent risk of further knee injury is most often in the best interest of the club, the coach and the athlete. It is, however, well-known that release for RTP after injury or surgery is a complex process depending on both medical and non-medical factors [42]. In the absence of specific criteria for PCL injuries, it seems reasonable to apply similar criteria as for RTP after ACL injury which means that RTP including full player-contact is allowed if the player has full active range of motion, >90% of the contralateral quadriceps and hamstring strength, >90% of the contralateral limb results in the running and hop test discharge test battery, no subjective instability or giving way and mentally ready without fear of reinjury (Table 21.2).

21.6.1 Non-Surgical Treatment

There are no studies reporting on RTP after non-surgical treatment of PCL injury in handball players, but clinical series on a variety of other team sport athletes show good subjective outcomes in general with a high return to sports rate even in high-level athletes in impact sports [32, 43, 44]. Since dynamic knee bracing usually is applied for at least 12 weeks in modern treatment of higher-grade PCL injuries, the expected time on the sidelines is around 4 months (Table 21.2) [32]. It is important to pay attention to achieve and maintain good patellofemoral balance and be attentive to any medial or patellofemoral complaints as these compartments are more at risk following a PCL injury [45].

21.6.2 Surgical Treatment

Like RTP after non-surgical treatment, the literature in this field is also sparse. In a retrospective follow-up of 60 PCL-reconstructed patients for at least 2 years, most team sport athletes could not return/continue with their sport after surgery and had to accept a lower physical activity level [46]. Interestingly, there were five handball players included in that study, and none of them had returned to handball at the time of follow-up. This finding needs, however, to be reproduced in other studies with handball players included before any firm conclusions can be drawn.

21.7 Long-Term Effects

PCL injuries are, as other intra-articular lesions such as ACL and meniscus injuries, associated with a higher risk of developing premature osteoarthritis in the knee. It has been shown that PCL deficiency exposes the knee to abnormal kinematics and contact pressures in the medial compartment and the patellofemoral joint, particularly with flexion beyond 70° [45]. A recent population-based 12-year follow-up showed that PCL-injured patients were, compared with an age- and sex-matched control group, associated with having a doubled risk of developing secondary meniscus injuries, six times increased risk of developing osteoarthritis and three times increased risk of requiring total knee arthroplasty [15].

21.8 Prevention

There are many intervention studies that have investigated the efficacy of different neuromuscular training (NMT) programmes on the risk of injury in adolescent and senior handball players, mainly in females [47–50]. Three studies evaluated the effect of NMT programmes on injuries in general as the main outcome [48–50], and one study investigated ACL injuries exclusively [47].

In the study of the highest scientific quality, 120 Norwegian clubs and 1837 female and male players aged 15–17 years were analysed in a randomised controlled trial (RCT) [48]. With regard to knee ligament injuries, there was a significant lower rate in the intervention group (three ACL injuries) than in the control group (ten ACL injuries, three PCL injuries and one MCL injury). No specific data on PCL injuries were reported in any of the other intervention studies. In absolute numbers, this Norwegian study suggests that there might be some preventive effect also for PCL injuries although the numbers were few.

It is unlikely that there will be a future RCT in handball on injury prevention having PCL injury as the main outcome in the sample size calculation due to its rarity. There are, however, other possible measures which can be introduced in observational studies. One example is to introduce rule changes or reinforcements of the existing rules such as what has been done in Australian rules football to reduce the number of PCL injuries [51]. Such initiatives by the stakeholders would be of potential value, especially since many of the fall-related PCL injuries, in our clinical experience, is a result of rule violations where the injured player is pushed from behind/in the back by an opponent which leads to a forward movement of the trunk and an uncontrolled landing with pretibial rather than patellofemoral impact.

Fact Box

Most of isolated PCL injuries can be managed non-surgically.
Further studies on rehabilitation protocols after PCL injury/surgery are warranted.

21.9 Take-Home Message

Sports-related PCL injuries are rare compared with other acute knee ligament injuries such as MCL and ACL injuries. The main challenge in the acute setting if a PCL injury is suspected is to distinguish whether the injury is isolated or combined with other significant knee injuries. The most common treatment for an isolated PCL injury is a non-surgical protocol with a dynamic knee brace at all times for at least 12 weeks and a stepwise progressive rehabilitation programme. Return to handball and other similar knee-demanding sports can usually be expected within 5 months after such treatment. Most of the recommendations lack solid evidence since the literature on treatment protocols and the RTP decision-making process following a PCL injury is scarce. Further high-quality and sport-specific studies in the field are thus urgently needed.

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22

General Aspects of Sports in Adolescents with a Special Focus on Knee Injuries in the Adolescent Handball Player

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22.1 Introduction

Many types of injuries may affect the knee of the pediatric and adolescent handball player (Table 22.1). Some of them are comparable to those of adult players, whereas others are typical to the growing individual. Adolescence is typically the age period where sports training load and performance increases significantly and where external forces applied to the knee joint become comparable to adult joint loads. On the other hand, the young athletes' body and mind are not comparable to an adult population [1]. Several so-called pediatric diseases may still be present. Therefore, it is of utmost importance that parents, coaches, team staff, and decision-makers in clubs, sports schools, and federations who take directly care or share responsibilities of adolescent handball

Table 22.1 Differential diagnosis of knee pain and knee injuries in adolescents

Differential diagnosis of knee pain in adolescents
Meniscus or chondral injury
Ligament injury (ACL, PCL)
Acute patellar dislocation
Acute fracture
Epiphyseal injury
Stress fracture
Prepatellar bursitis
Osteomyelitis
Septic arthritis
Juvenile rheumatoid arthritis
Tumors
Osteochondritis dissecans
Popliteus cyst, meniscal cyst
Discoid meniscus, lateral meniscus instability
Patellofemoral instability
Patellofemoral pain syndrome (anterior knee pain)
Osgood-Schlatter disease
Sinding-Larsen-Johansson disease
Mediopatellar plica syndrome
Patellar tendinopathy
Hemophilia
Referred pain from spine or hip diseases (i.e., femoral head epiphysiolysis)

The list covers both adult and pediatric diseases

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players are aware of the fact that this age group has some particularities which make them susceptible to sustain specific injuries. The current chapter provides an overview of some general aspects in youth sports with a special focus on knee injuries and diseases but also on existing knowledge gaps.

22.2 Sports Injuries in Children and Adolescents

The burden of sports injuries in the EU in 2012 comprised 7000 fatalities, 600,000 hospital admissions, 5,200,000 outpatient hospital treatments, and 2,600,000 other medical treatments. Twenty-five percent of them affect children and adolescents. Kahl reported roughly one injury out of three in children coming from sports, with 32% of all injuries in the 5–14 years' age group and 39% in the 15–17-year-old group [2]. The American Orthopaedic Society of Sports Medicine (AOSSM) reported that every year, more than 3.5 million children aged 14 and younger are treated for sports injuries. It is especially surprising that nearly 50% of all injuries sustained by middle and high school students during sports were overuse injuries. This may be the result of the increasing competitiveness of youth sports, which can be seen on a global scale in many different types of sports.

22.3 Injury Surveillance in Youth Sports

There has been a steady growth in major high level international, continental, and global competitions for youth. Such competitions have stimulated lofty performance-oriented targets to which younger athletes can aspire. In addition, many youngster and their parents have high aspirations for US college scholarships. Sanctioned and overseen by various or individual international associations, federations, and universities, these events may be fruitful in an athlete's development toward high injury risk competitions, but from a health perspective, they may also be seen as stepping stones. Unfortunately, there are no mechanisms currently in place that increase scientific knowledge of sports injuries and stimulate injury monitoring and prevention in this young population. For those physicians who are treating young athletes, the paucity of systematic injury surveillance and prevention programs in the field is surprising. Care must be taken to avoid compromising the future of young athletes not only in their development through higher levels of competition but more importantly their prospect of leading a healthy and pain-free life beyond sport. It is unacceptable that potentially preventable injuries be the cause of reduced physical capacity later in life. Raising awareness of sports injuries within the greater community beyond sports and in the political arena in particular will have far reaching benefits for citizens of all ages involved in physical activity.

An example of injury surveillance in young athletes (Fig. 22.1) has been conducted in a sports school in Luxembourg on 241 athletes in various sports [3–5]. Injuries were recorded on a time-loss basis, and most of them were of minor or moderate nature. Over a period of 4 years, a total of 1481 injuries had been collected, resulting in an incidence of 1.5 injuries/athlete/year. The knee was affected by 311 injuries (21%), of which 81 (6%) were major, resulting in an incidence of severe knee injuries of 8200/100,000 young athletes. Eight anterior cruciate ligament (ACL) injuries were recorded, resulting in an annual incidence of 830/100,000 young athletes, which is approximately ten times higher than in an adult population. A correlation between injury risk and training intensity could also be established. Given that handball is a high-risk sport for knee injuries, those figures may be even higher than in this multisport example. In addition to this, risk indicators for injury could be elaborated. More than 10 days without rest, >50% intense training sessions, participating in competition despite an injury, >7 days indication of an injury or a symptom, and the presence of recurrent injuries were indicators appearing automatically as yellow or red flags in an athlete's electronic monitoring system in order to alert athletes and their environment. This shows that monitoring injuries, estimating the injury risk, and implementing strategies for injury prevention could be of utmost importance for the health protection of young high-performing athletes. So far, similar statistics and efforts are unfortunately lacking or only at its very beginnings so far in youth handball [6, 7].

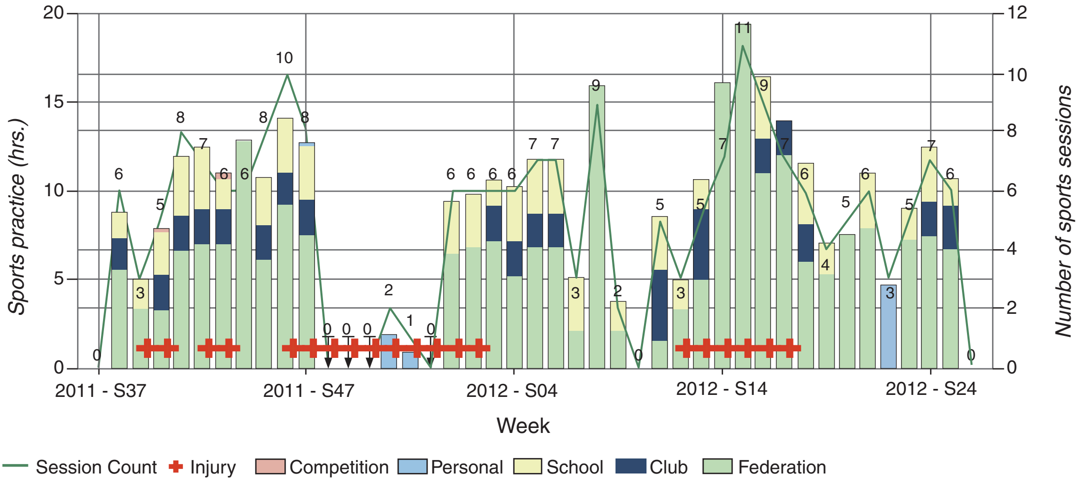

Fig. 22.1 Example of an individual training and competition load chart in a young handball player (left, hours of weekly sports practice; right, number of weekly sports sessions) based on data from [4]. The chart illustrates nicely the accumulation of school, club, and federation sessions. The red crosses indicate the periods of pain and/or injury which did not necessarily correspond to periods of rest. This type of systematic injury surveillance should become mandatory in adolescent elite sports in order to protect the health of young athletes

22.4 Preparticipation Examination

In many countries, no preparticipation examinations are required for access to competitive youth sports. To our knowledge, no data exist in this respect for handball. In addition to this, no internationally accepted standards have been established with respect to such health examinations in youth sports despite the fact that a systematic examination results in 5.5% of restricted eligibility of young athletes and an exclusion from youth sports in 0.4% of them [8]. It would be useful that national and international sports federations would work on such requirements, especially before granting access to international competitions.

Preparticipation assessment for knee injuries requires history taking for any knee conditions and symptoms. In this respect, it is well known that non-traumatic ACL injuries as well as patellar dislocations are frequent and do also have high recurrence rates in adolescents and young adults. Family history and generalized joint laxity have been recognized as risk factors for both types of injuries. Generalized laxity is generally documented according to the Beighton score [9, 10]. At the knee joint, it is expressed by knee hyperextension (recurvatum). A score of >4/9 is considered as pathologic.

22.5 Knee Growth and Maturation

Understanding the biological environment of the adolescent knee requires specific knowledge of growth in general and knee growth in particular. The examiner must consider the large variation of maturity levels at an identical chronological age. Indeed, large interindividual differences between chronological and skeletal ages exist during adolescence, leading to significant biological differences in youth sports categories which are based on chronological age only and not on physiological maturation (Bergeron). An evolution in this respect may therefore be considered in the future in order to make young athletes compete in categories of physiological maturation. Similar efforts have been implemented successfully in youth football in some countries [11].

The growth plates around the knee at the distal femur and the proximal tibia are responsible for approximately 60% of the longitudinal growth of the lower extremity. With approximately 4 cm/year, knee growth velocity is high but constant during childhood from age 3. It decreases before

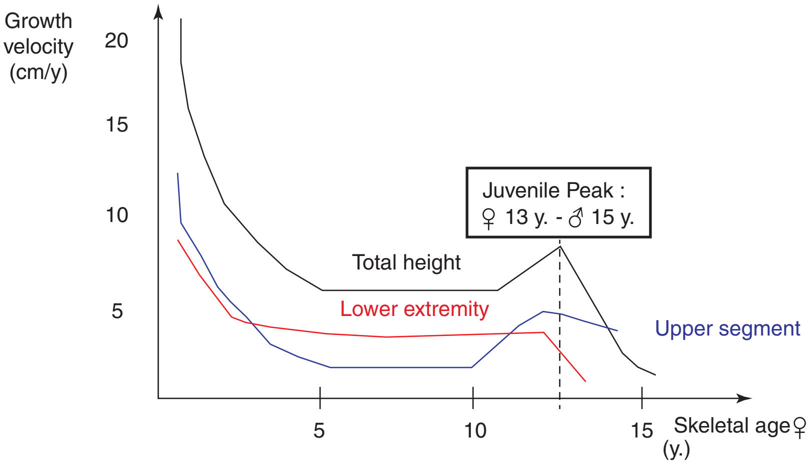

Fig. 22.2 Knee growth velocity chart in relation with skeletal age (here in girls). The growth speed of the knee (red line) starts to decrease before the occurrence of the juvenile peak or growth spurt. The latter originates mainly from spinal growth (blue line: growth of the upper segment). In boys, the juvenile peak occurs 2 years later (Modified from [67])

the occurrence of the growth spurt, at skeletal age 13.5 in girls and 15.5 in boys (Fig. 22.2). From that moment, it will take approximately 1 year before longitudinal knee growth will come to an end. The growth spurt, which is mainly caused by spinal growth, starts shortly after the decrease of knee growth velocity. As a consequence of an increased susceptibility of the growth plate to direct mechanical stress as well as repetitive physical strain, a significant increase of sports injuries around the knee has been documented around this phase [12]. The Watson-Jones fracture of the tibial tuberosity is a typical apophyseal fracture susceptible to occur at this age. Similarly, the Osgood-Schlatter or the Sinding-Larsen-Johansson diseases appear at the same moment.

In some sports, which generate loading of some specific body parts, fatigue-fracture-like changes have been well documented. This is the case of the gymnast's wrist, a fatigue fracture of the physis of the distal radius which is caused by repetitive landing on the hands [13], or the little league shoulder and elbow in baseball, a fatigue fracture of the proximal humeral growth plate, which is caused by repetitive throwing [14, 15]. The alignment of the lower limb in the frontal plane occurs during the phase of adolescence, which may also be a direct cause of this growth plate susceptibility. Children's knees are generally straight or in light valgus. While girls maintain their lower limb alignment, boys may develop varus alignment around the end of their growth spurt [16]. These bowleg deformities occur from 13 to 15 years of age and are related to high-impact sports participation [17]. This may be due to the fact that excessive compressive loads to the proximal medial tibial physis lead to restricted physeal growth [18]. Care should therefore be taken to avoid a too intense and repetitive mechanical loading of the growth plates during this phase in adolescents.

Prior to adolescence, physiologic knee laxity is high (Fig. 22.3). If children would not be able to cope with it, the number of ACL injuries would be excessively high during childhood, which is not the case. On the contrary, it is during and after adolescence, when the knees get stiffer, that a dramatic rise in noncontact ACL injuries has been documented over the last decade in the ACL reconstruction registries from Scandinavia and North America (Fig. 22.3). This indicates that adolescents may struggle with their neuromuscular control at a time where they grow and where sports performance is increasing. Neuromuscular control in adolescence has nevertheless been poorly investigated so far. A recent investigation showed that girls change their landing technique around their adolescent growth spurt in a sense that it has the potential to increase the risk to sustain a noncontact ACL injury with a combination of weak hip abduction, increased hip flexion, decreased knee flexion, and knee valgus at landing [19]. It should

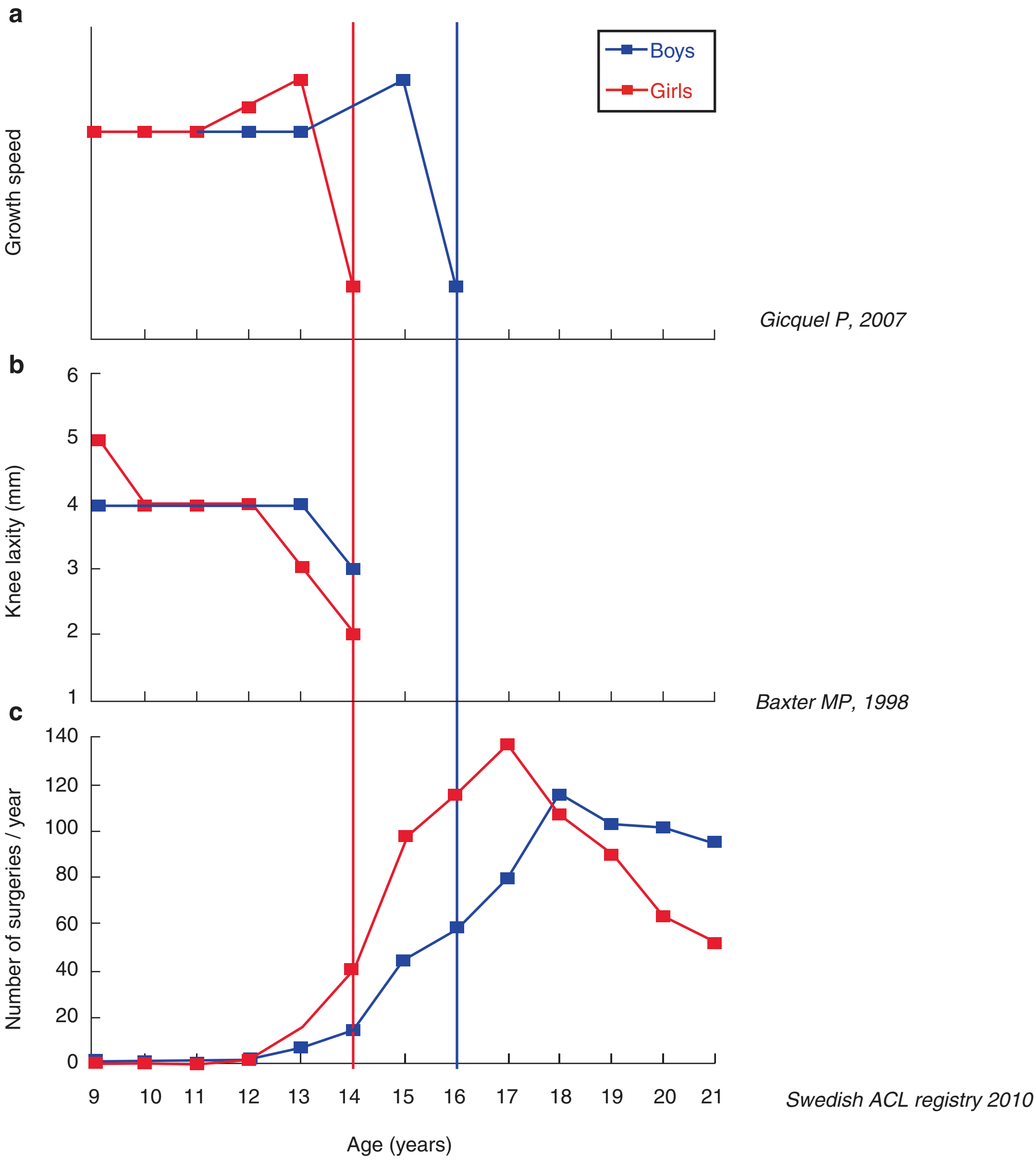

Fig. 22.3 Superimposition of three charts delivering essential information on knee growth and ACL injury risk in adolescents. (**a**) represents the growth speed of the knee and indicates that knee growth stops at 14 years in girls and 16 in boys (Modified from [67]). (**b**) shows the high physiologic knee laxity in children which is decreasing at the same time that the knee growth velocity decreases (Modified from [68]). (**c**) shows the rising curve of ACL reconstructions from the Swedish ACL registry in 2010 [20]. These figures increase from the moment where the knees have stopped growing and when they have reached adult stiffness. The reason for this dramatic rise in ACL injuries is not fully understood yet

also be known by coaches taking care of adolescent athletes that skeletal development generally precedes muscle and tendon growth, leading to a permanent change of joint-loading lever arms and imbalances of muscle chains, adding to the complexity of the task of balance control at this age. For the multiple reasons cited above, training and competition loads should be adapted to the young athlete during this phase of increased injury susceptibility.

22.6 Types of Injuries

Knee pain in children and adolescents should always be considered with caution and be investigated. Clinicians should keep in mind that knee pain can also be referred from adjacent structures and particularly from the hip joint. In this context, a thorough clinical examination and standard knee radiographs should be performed. Although negative in a majority of cases, they do still represent the primary method of investigation. They may show osteochondral lesions like the osteochondritis dissecans or more rare entities like tumors. Magnetic resonance imaging (MRI) should be considered in a second step.

All intra- and extraarticular structures of the knee may be injured during handball, and the list of causes of knee pain and injuries in adolescents is extensive (Table 22.1). Some of the injuries and diseases are specific for patients with open growth plates, whereas others are similar to adult problems. This injury may be acute or chronic. Handball-specific data only exist for ACL and shoulder injuries [6] which are the most frequent severe injuries in handball. These data were generated over the last decade from Scandinavian ACL reconstruction registries [20–29]. Together with ACL tears, meniscus injuries and patellar dislocations are the most frequent acute injuries in children and adolescents. Associated congenital factors like a discoid meniscus, trochlear dysplasia, or an ACL agenesis must always be ruled out in these patients and included in their therapeutic algorithm.

22.6.1 Ligament Injuries

22.6.1.1 ACL Injuries

Three types of ACL injuries must be considered in children and adolescents: bony avulsions, ligamentous tears with open growth plates and ligamentous tears after growth plate closure.

Older papers suggest that **bony avulsions** are more frequent than ligamentous injuries in children under the age of 12 [30], but this may not be the case currently. They have been classified into four stages according to the and McKeever classification [31], which was completed by Zaricznyj [32]. Grade 1 injuries may be treated nonoperatively with a plaster immobilization in extension for 6–8 weeks. Grade 2, 3, and 4 injuries should undergo surgical treatment. Fragment fixation is generally performed arthroscopically, either through sutures or temporary screw fixation. For a good repositioning of the fragment, the surgeon should take care to place the bony fragment underneath the intermeniscal ligament.

Ligamentous injuries in the presence of **open growth plates** represent less than 5% of all ACL injuries (Fig. 22.4). Their incidence seems to increase over the last two decades which may be due to improved clinical and diagnostic skills but also to the increase of participation in sports at risk like handball. Most of these ACL lesions are noncontact injuries. In the acute setting, hemarthrosis is often present. The diagnosis is made clinically by using the Lachman and pivot shift tests. Standard radiographs should exclude associated bony injuries. MRI is used to confirm the ACL injury as well as to rule out meniscus and cartilage damage.

Return to a *pivoting* sport like handball cannot be recommended without ACL reconstruction because of the high risk of secondary meniscus and cartilage lesions caused by the pathological knee laxity. Even signs of secondary osteoarthritis have been reported in chronically ACL deficient patients with open growth plates. For many years, surgical reconstruction was not recommended either, because of the presence of growth plates and the risk of surgically induced secondary growth changes. Over the last 10–15 years, surgical techniques for ACL reconstruction with open growth plates have evolved significantly and have been proven safe, provided that surgery was performed in a technically correct way. The indication for surgery is given in the presence of a meniscus injury, giving way episodes and a subjective feeling of instability which may not be controlled by physical therapy. Although return to handball is often possible after ACL reconstruction with open growth plates, return to elite level sports has not yet been reported. In addition to this, the rate of recurrent tears or ACL injuries

Fig. 22.4 Anteroposterior and lateral radiographs of the left knee of a 13-year-old handball player showing wide open growth plates. The boy had sustained a noncontact ACL injury during handball. He had a positive family history of ACL injuries (father, mother, and brother), was hypermobile (Beighton score > 4/9), and had a high remaining growth potential. The lower radiographs show his knee after transphyseal four-strand-hamstring ACL reconstruction with extracortical graft fixation. He was able to return to handball 1 year after surgery but tore the ACL of his other knee 3 years later which made him stop playing handball

on the contralateral knee is very high and has been estimated up to 33%. These arguments illustrate that therapeutic decision-making can be difficult in these young patients.

If a decision for surgery has been made with the young athlete and his or her parents or legal representatives, it should be thoroughly planned. Skeletal age determination (i.e., with a standard radiograph of the left hand) helps to objectivate remaining knee growth. Preoperative long leg standing radiographs of both legs determine limb alignment and rule out pre-existing leg length differences. Several types of surgery have been discussed. Ligament repair (i.e., sutures) has been proven unsuccessful and cannot be recommended. The technical difficulty of the so-called pediatric procedures is related to the presence of the growth plates of the distal femur and the proximal tibia. They do not allow to transfer the established adult techniques to pediatric and young adolescent patients. Therefore, a large variety of intraarticular ligament reconstruction procedures have been described, and rules for technically safe pediatric ACL reconstructions have been established [33]. Applying them results in very low rates of growth-related complications [34]. Meniscus preservation through adequate repairs is of utmost importance in these procedures since long-term OA development is strongly related to the integrity of the menisci. Clinical results are good, although recurrent tears are more frequent than in an adult population [35]. Return to sports rates have been insufficiently evaluated, and no specific results are known for handball. Timing for return to sports should be considered with caution since the majority of second ACL injuries occur within the 2 first years after ACL reconstruction. Therefore, a thorough rehabilitation of 9–12 months including a sports-specific preparation for return to sports must be recommended in this young athletic population [36].

Ligamentous injuries with closed growth plates are the most frequent type of ACL injuries seen in adolescent handball players. Most of them are noncontact injuries. Female players have a two to five times higher risk to sustain such an injury, although the absolute amount of injuries may be higher in males through their increased sports participation. It has been shown that the desire to return to sport is the first motivation for players to undergo surgery. In a majority of patients, ACL reconstruction allows for a return to an unrestricted sports participation, but it cannot prevent later development of knee OA, especially in the presence of cartilage lesions or in case of partial or (sub)total meniscectomies. Returning to handball without ACL reconstruction has been reported but cannot be recommended on a general scale. Recent investigations from Scandinavian registries, but also from Australia and North America, have shown that patients who undergo an ACL reconstruction in adolescence and young adulthood have a 33% probability to sustain a second ACL injury, be it on the injured or on the contralateral knee. Therefore, it appears important to evaluate the risk for second ACL injuries from the start. A positive family history; generalized joint laxity, as expressed through knee hyperextension (recurvatum); as well as the loss of a meniscus or the presence of a so-called lateral notch sign on lateral radiographs increase the risk either of a recurrent ACL injury or an ACL tear of the non-injured knee. ACL reconstructions in adolescents do not differ from the techniques used in adults and are developed more in depth in another chapter of this book.

In terms of secondary prevention in general and more precisely in return to handball participation, the development of specific re-athletization pathways under the guidance of specially trained physiotherapists or athletic trainers with a thorough knowledge in sports medicine should be encouraged on a more general scale in this particular age group [37, 38].

22.6.1.2 Posterior Cruciate Ligament (PCL) Injuries

Injuries of the PCL, both in patients with open physes and after growth plate closure in adolescents are rare [39]. In the former, bony avulsions are more frequent than ligament injuries. They are more difficult to diagnose than ACL injuries, which explains that their diagnosis is often delayed. The injury mechanism is often a forced hyperextension or direct anterior trauma to the knee. Subjective instability is rarer than in

ACL injuries, except if collateral ligament injuries are associated. In PCL and posterolateral corner injuries, a typical varus thrust phenomenon can be observed during gait after some time. Provocative tests like the posterior drawer or the reversed pivot shift tests are generally positive. The association of a posterolateral corner injury should be systematically ruled out with the so-called dial test which evaluates external rotation of the foot in 30° and 90° of knee flexion, the patient lying in the prone position. In the acute setting, clinical assessment in association with MRI is sufficient to make a complete diagnosis. In chronic cases, stress radiographs should be added to the diagnostic portfolio. In a PCL injury with a side-to-side difference in the posterior drawer of more than 8 mm, surgical treatment should be considered [40]. In rare cases, examination under anesthesia and arthroscopy may be used to complete the diagnostic picture.

In bony avulsions, the dislocated fragments should be fixed early by using either an open or an arthroscopic technique. Isolated grade 1 injuries can often be compensated with good rehabilitation and quadriceps strengthening, whereas in isolated grade 2 and 3 and particularly also in combined injuries, surgical treatment should be considered. Successful return to sports is possible after isolated or combined PCL reconstructions, but little high-quality data are available on the short- and long-term outcome after such severe knee injuries in adolescents.

22.6.1.3 Collateral Ligament Injuries

Medial collateral ligament (MCL) injuries are less frequent in handball in comparison to sports-like alpine skiing, American football, or European football. They may be isolated or combined with other ligament injuries like ACL tears. If the growth plates are still open, they can appear as bony avulsions rather than ligament injuries. According to Fetto and Marshall, they are classified into three grades [41]. Grade 1 and 2 injuries are always treated conservatively, whereas grade 3 injuries may require surgical repair or reconstructions [41, 42]. Grade 3 injuries are rarely isolated and can be considered as pathognomonic for a combined cruciate ligament injury. Lateral collateral injuries occur less often than their medial counterparts. They are rarely isolated, and most of them are combined with injuries of the posterolateral complex (including popliteal tendon and popliteofibular ligament injuries). As such, they do generally require surgical reconstruction and long rehabilitation procedures.

22.6.2 Non-Ligamentous Soft Tissue Injuries and Disorders

22.6.2.1 Meniscus Injuries

In small children, the meniscus is highly vascularized, from its periphery to the central zone, whereas “adult” meniscal vascularity is present approximately from age 11 and is located essentially in the peripheral third of the menisci [43]. In association with ACL injuries, meniscus lesions are present in approximately 50% of the cases. Their integrity strongly influences the long-term prognosis of the knee with respect to OA development. In stable knees, isolated, traumatic meniscus tears in children under the age of 10 are exceptional. The most frequent tear types in adolescents are bucket handle and longitudinal tears. More specific lesions are radial tears which are often seen on the lateral meniscus as well as lateral meniscus instabilities. The injury mechanism often associates knee rotation and flexion. Symptoms are knee effusions, pain, motion deficits, and repetitive blocking mechanisms. Clinical meniscus signs may be positive and are nonspecific. Imaging procedures include standard radiographs to rule out associated bony injuries as well as MRI.

The main goal of meniscus surgery in young athletes is to repair the meniscus whenever possible. The techniques of meniscus repair have significantly evolved over the last years allowing surgeons to perform most surgeries with minimally invasive all-inside techniques [44]. The reason why meniscal repair should be attempted as a primary target is the improved vascularization and hence the better healing potential of menisci in children and adolescents, as well as the deleterious long-term effects on the development of OA in case of meniscus loss.

In the absence of a fully validated and globally accepted rehabilitation protocol, most surgeons allow for full weight bearing as tolerated with a knee blocked in full extension. Passive flexion is permitted to 90° during the first 4–6 weeks, and deep squatting should be avoided for up to 4 months. Full return to pivoting sports practice is generally acquired between 4 and 6 months. The same principles apply in case of an associated ACL reconstruction. The results of meniscus repair in children and adolescents are good with approximately 80% healing rates.

22.6.2.2 Popliteal Cysts, Meniscal Cysts, and Discoid Meniscus

Popliteal cysts may develop between the tendons of the gastrocnemius and semimembranosus muscles and represent a bursal type of swelling which is rarely related to an intraarticular pathology like cartilage or meniscus lesions in children and adolescents. Most of them are asymptomatic. Their prevalence has been reported to be 2, 4% [45]. Rare symptomatic cases should be treated nonoperatively since most of them dissolve spontaneously over time.

Meniscal cysts may be seen in adults and adolescents, often in association with meniscal injuries. Cysts of the lateral meniscus are more frequent, often in association with horizontal meniscus lesions [46]. Patients complain of mechanical pain as well as knee swelling. In rare cases the cyst may be palpated at the height of the joint line. The treatment should focus on the origin of the meniscus lesion and eventually can be arthroscopic or open.

Discoid menisci (DM) are rare and mostly located on the lateral side. Their prevalence has been estimated at 3–5% and is higher in Asiatic populations. Depending on their morphology, they may be considered as complete (type I), partial (type II), or without fixation of the posterior horn to the tibia (type III) [47]. In the latter, stability of the posterior horn is maintained through a strong meniscofemoral ligament. Typical symptoms are episodes of blocking and sometimes swelling without major symptoms of pain. Anterior dislocation of the DM can lead to an extension deficit. Snapping can be reproduced during clinical examination. Due to its thickness and inhomogeneous collagen structure, DM are prone to secondary lesions, causing typical meniscus symptoms. Due to their frequent absence of fixation to the peripheral capsule, they may easily dislocate either anterolaterally or posterocentrally [48]. Standard radiographs are normal or nearly normal. MRI is the diagnostic method of choice. Asymptomatic DM which have been diagnosed by hazard require no specific treatment. The treatment goal of symptomatic DM is to preserve as much meniscal tissue as possible. Therefore, a careful arthroscopic resection of the injured tissue (saucerization) needs to be combined with repair and capsular attachment of the remaining tissue. Rehabilitation is similar to other meniscal repair procedures.

22.6.2.3 Chondral and Osteochondral Lesions

The spectrum of chondral or osteochondral injuries reaches from an isolated, traumatic lesion to chronic, overuse-related lesions of degenerative nature. They may appear as so-called flake fractures, often as a consequence of a rotation and compression injury, and are either isolated or associated to other injuries like ACL tears. In case of a minor trauma, an associated bone bruise may be described in MRI. If a cartilage or osteochondral flake can be identified, and given the high healing potential in pediatric and adolescent patients, fragment fixation should be attempted whenever possible [49]. This can be done either with metal or resorbable interference screws or resorbable pins.

22.6.2.4 Juvenile Osteochondritis Dissecans (JOCD)

JOCD is a frequent entity leading to the necrosis of the subchondral bone which is located either on the lateral aspect of the medial femoral condyle (70%), the lateral femoral condyle (20%), the trochlea, or the patella [50]. In approximately 10% of the cases, JOCD may be present in both knees. Its prevalence is around 15–30 cases per 100,000 young athletes, with a higher prevalence in males. Its origin is not fully known. It is hypothesized that it may be mainly microtraumatic, but some family predispositions have been reported as well. In its early stages, the JOCD often becomes symptomatic in athletes through the generation of nonspecific chronic knee pain and sometimes swelling [51]. In its late stages, the JOCD may become apparent through painful blocking if the osteochondral fragment is in the process of loosening or if it has dislocated. If a JOCD is diagnosed and the osteochondral fragment is still in place, the questions of the stability of the lesion and its potential for spontaneous healing must be addressed. These two factors decide on the future operative or nonoperative management. Currently, several nomograms are under investigation to evaluate the prognostic potential of clinical, radiographic, and MRI criteria of the disease. The main prognostic factor is the size of the lesion, whereas the prognostic potential of the age of appearance of the disease is still controversial [52, 53].

Nonoperative treatment may last up to 12 months. During this period, strenuous sports activities with repetitive joint loading should be avoided. The type of surgical treatment mainly depends on the integrity of the overlying cartilage layer. If it is intact, retrograde perforations of the subchondral bone should be preferred to antegrade drilling procedures in order to preserve cartilage integrity. If the fragment is dislocated or in the process of dislocation with a documented cartilage damage, the fragment should be fixed, and the fibrous tissue covering the bed of the fragment should be debrided if possible. Fixation can be permanent through absorbable screw or pin fixation or temporary with metal screw fixation. The former technique bears the disadvantage that fragment fixation may not be strong enough to allow for bone healing. The latter requires a second surgery to remove the metal screws but has the advantage to readdress the lesion if no or only partial fragment healing has occurred. In some extensive cases, subchondral cancellous bone grafting may become necessary to fill the defect. In the rare cases of a multifragmented cartilage or if the fragment cannot be fixed, an alternative cartilage and subchondral reconstruction technique like osteochondral grafting or autologous chondrocyte transplantation must be considered after finished growth. Large fragment removal without defect filling with the goal to rapidly recover knee function and return to sports performance is not an option in the long term for young athletes. Results are generally good with good return to sports rates, with a more limited prognosis in case of extensive lesions and major reconstruction surgeries.

22.6.3 Injuries and Disorders of the Extensor Mechanism

22.6.3.1 Patellar Dislocations and Instabilities

With an estimated incidence of 43/10,000, patellar dislocations are frequent injuries in young athletes. In addition to this, the redislocation rate is as high as 67% [54, 55]. A large number of anatomical risk factors have been identified. They are summarized in Table 22.2. Real traumatic patellar dislocations are rare and require a direct blow to the medial side of the patella to induce a lateral dislocation. Most of them

Table 22.2 Risk factors for patellofemoral instability in pediatric and adolescent athletes

Contributing factors to patellofemoral instability
Bony factors
* Valgus knee
* Patella alta
* Dysplasia of patella or lateral femoral condyle
* Trochlear dysplasia
* Lateralized tibial tuberosity
* Excessive femoral antetorsion
Ligamentous factors
* Generalized joint laxity/hypermobility
Muscle factors
* Hypoplasia or hypotrophy of vastus medialis obliquus muscle
* Dystrophy, atrophy, or paresis of medial quadriceps (nerve roots L3/4)
* Infantile cerebral palsy
Systemic diseases
* Ehlers-Danlos syndrome
* Arthrogryposis
Adequate trauma
* Contact injury with mediolateral impact
* Trauma in knee flexion, valgus, and internal rotation with fixed foot

are non-traumatic. They may either be acute or chronic or be present under different forms like patellar maltracking. They all have in common that the patella, which is located proximal to the trochlear groove in the extended knee, cannot freely engage into the trochlear groove during the first 20–30° of knee flexion. Depending on the initial position of the patella (i.e., too high in case of patella alta), the underlying bony structures (flat or even concave groove, presence of a trochlear bump at groove entrance, abnormal form of the patella), the tightness and integrity of the soft tissue structures which retain the patella in place (of which the medial patellofemoral ligament (MPFL) is the most important one), and the position of the foot (external rotation tracks the patella laterally), the patella may start its excursion from knee extension to flexion lateral of the trochlear groove and later fail to reengage into the groove and hence dislocate laterally. In case of acute or recurrent dislocations, the most frequent injury mechanism is similar to noncontact ACL injuries with the knee being in early flexion and a valgus position, the femur internally rotated, and the foot in a fixed, externally rotated position.

The most frequent clinical signs in acute, first-time dislocators are bloody effusions, swelling, pain over the medial soft tissues, reduced range of motion, and a positive apprehension test. The latter is the most valuable test in chronic/recurrent instabilities. Combined chondral or osteochondral lesions or flake fractures can be found in more than 90° of the cases. They should systematically be ruled out with standard radiographs and MRI. They are located either on the patella or on the lateral femoral condyle. An attempt to fix them is recommended whenever possible, either in isolation or in combination with an MPFL reconstruction. Primary repairs of the MPFL have poor results and cannot be recommended. Lateral retinacular releases should be avoided whenever possible, in order to prevent iatrogenic medial patellofemoral instabilities. In case of open physes, a pediatric MPFL reconstruction technique should be used to avoid violation of the medial distal femoral growth plate and secondary growth disturbance [56]. It provides good and reproducible results and improves patellofemoral biomechanics [57]. It should be noted that the femoral insertion point of the MPFL is located distally to the physis because of its epiphyseal origin [58]. In the absence of major soft tissue and chondral injuries, a nonoperative treatment with immobilization in a brace in full extension should be attempted for 4 weeks. Rehabilitation periods may be as long as for ACL reconstruction procedures, especially if surgery has been performed.

After growth plate closure, a trochleoplasty may become necessary in the presence of a major trochlear dysplasia. This is major knee surgery which should not be performed primarily. It is often associated with other surgical steps like MPFL reconstruction or tibial tuberosity osteotomy to normalize the distal patellar tendon insertion. Return to performance-oriented sports practice after this type of surgery is generally not recommended.

22.6.3.2 Anterior Knee Pain (AKP; Synonym, Patellofemoral Pain Syndrome)

This purely descriptive terminology summarizes several diseases which may be of patellofemoral origin or which may cause pain that is projected to the patellofemoral joint [59, 60]. Symptoms may start at the prepubescent age but are very frequent in adolescence and particularly in female athletes. Pain can be activity-related and/or be present at rest, especially in a sitting position with flexed knees or during stair walking. Knee range of motion, leg length, gait, and lower limb torsion need to be analyzed clinically. Structural causes like cartilage lesions of the patella or trochlea or a painful mediopatellar plica should be ruled out through clinical examination (palpation, patellofemoral crepitation; Zohlen sign) and radiographic procedures (standard radiographs, MRI, and in some rare cases arthro-CT scan). In most of the cases, AKP is of functional origin and is caused either by muscle imbalances or insufficiencies of one or several muscle groups, mainly of the muscles of the thigh and hip abductors. Lower extremity muscle strength and fatigue should be documented objectively, either through specific isokinetic testing or through standardized functional tests like hop tests and video analysis of squatting or similar movement patterns.

In many patients, the spontaneous evolution of AKP is positive. In the presence of a well-documented retropatellar cartilage lesion, a careful arthroscopic debridement may be recommended. A painful mediopatellar plica should first be addressed nonoperatively, mainly through physiotherapy. Intraarticular injections or even arthroscopic plica resection can only be recommended after a failed and well-performed nonoperative treatment of several months. In case of documented functional deficits and disorders, physiotherapy and specific muscle reinforcement should be performed. Neuromuscular training can be very helpful to improve knee kinematics [61]. The patients and their parents need to be thoroughly reassured and informed that this may sometimes be required for several months. Surgical treatment is only recommended in the presence of a documented structural lesion. In the past, either open or arthroscopic lateral retinacular releases were often performed with the simplistic hypothesis to reduce pain through patellofemoral pressure reduction. In the absence of clearly documented structural lesions, this procedure cannot be recommended anymore.

22.6.3.3 Osgood-Schlatter and Sinding-Larsen-Johansson Disease

Osgood-Schlatter disease is the most frequent traction apophysitis in pediatric and adolescent patients, with a peak at 13–14 years in boys and 10–11 years in girls. It is probably caused through repetitive stress at the distal patellar tendon insertion at the time of the development of a secondary ossification center of the tibial tuberosity. The onset of symptoms is progressive, often starting after exercise. Pain at palpation of the tibial tuberosity is the most frequent clinical sign. Sometimes swelling can be observed. Standard radiographs may show a multifragmented tibial tuberosity and sometimes apparently loose, well delineated bony fragments at the distal patellar tendon insertion. Nonoperative treatment comprises relative rest over a period of several months. Static quadriceps training and physiotherapy are generally recommended in the most painful stages. In extremely painful conditions, immobilization can be considered for several weeks. Local corticoid injections are contraindicated. Sports activity is not a strict contraindication, but explosive quadriceps exercises should be avoided, and activities requiring a less strenuous stress on the tibial tuberosity like biking and swimming can be recommended. In most of the cases, the Osgood-Schlatter disease is a self-healing condition which comes to an end when bony integration of the tibial tuberosity will be completed. On rare occasions, remaining ossicles at the distal patellar tendon insertion stay symptomatic and need to be surgically removed after the end of the growth period. Sinding-Larsen-Johansson disease is a traction apophysitis which is located at the distal pole of the patella. In most aspects, it is similar to the Osgood-Schlatter disease.

22.6.3.4 Patellar Tendinopathies [62]

The knee has been shown to be chronically painful in 16–20% of adult handball players [63, 64]. To our knowledge no such statistics exist in adolescent athletes. A frequent cause of chronic anterior knee pain in handball is caused by proximal patellar tendinopathy. It occurs after growth plate closure and is frequently associated with chronic quadriceps contraction and shortening. Therefore, prevention exercises comprising quadriceps stretching are important. Clinically, a sharp pain can be provoked on palpation of the distal patellar pole in full extension of the knee and quadriceps relaxation. MRI often shows a partial necrosis of the proximal patellar tendon as well as signs of inflammation at the distal pole of the patella. Associated retropatellar cartilage lesions should be excluded. Although it may extend over several months, nonoperative treatment is often successful. It is similar to the treatment of adult players. Corticosteroid injections are severely contraindicated because of the risk of a cortisone-induced tendon rupture. Surgical treatment of patellar tendinopathy consists of an arthroscopic debridement of the distal patellar pole as well as localized tendon removal. Immobilization is generally not required after this procedure and return to sports can be considered from 4 to 6 weeks.

22.6.3.5 Patella Fractures

Fractures of the patella are rare in children and young adolescents. They may be caused by a direct trauma or forced quadriceps contraction against the flexed knee. Most of them are transversal. Non-dislocated fractures should be immobilized in a cast in full extension for 6 weeks. Dislocated fragments should be treated with open reduction and internal fixation.

A specificity in athletes with open physes is an osteoperiosteal avulsion fracture of the distal pole of the patella, the so-called patellar sleeve fracture (Fig. 22.5). The sleeve can extend posteriorly into the patellar cartilage. Therefore, an MRI and/or arthroscopic assessment can be recommended in these rare cases. Dislocated fragments can be fixed with Kirschner or cerclage wires. Direct fixation to the distal patellar pole can be considered in case of small fragments.

Fig. 22.5 Sleeve fracture. Patella sleeve fracture in a 12-year-old boy. Note the avulsed small bony fragment from the distal pole of the patella and the secondary patella alta

22.6.3.6 Fractures of the Tibial Tuberosity [65]

Avulsion fractures of the tibial tuberosity occur before growth plate closure at 14–16 years in boys and 2 years earlier in girls. They are frequently accompanied by signs of Osgood-Schlatter disease. Standard lateral radiographs of both knees are helpful to evaluate the normal growth plate and the patellar height. Non-dislocated fragments should be immobilized in a cast in full extension of the knee for 6 weeks. Open reduction and internal fixation are recommended in dislocated fragments. Postoperative immobilization in a cast should be considered for 4–6 weeks. Range of motion exercises should be started after cast removal.

22.6.3.7 Injuries of the Distal Femoral and Proximal Tibial Physis

In young players with open growth plates, fractures of the distal femoral and proximal tibial physis have a serious complication potential because of the high amount of longitudinal growth originating from them [66]. The distal femoral physis is responsible for 70% of the total length of the femur and 37% of the length of the lower extremity. In case of abnormal growth after a physeal injury, significant leg length differences and axial malalignments can be expected. Physeal injuries occur in acute, often high energetic trauma mechanisms and cause immediate major pain, functional limitation and in some cases, even major limb deformity. It should be kept in mind that the popliteal vessels may be injured as well if a hyperextension trauma mechanism occurs. Standard radiographs are generally sufficient to diagnose the fracture and classify it according to one of the five fracture types of the Salter and Harris classification.

Treatment depends on the amount of dislocation and intraarticular fragment extension. Non-dislocated fractures are generally treated nonoperatively in a cast for 2–3 weeks. Dislocated fractures (Salter I and II) need a closed reposition under anesthesia. In such cases, correction of malrotation and frontal malalignment is more important than in the sagittal plane. Through the remaining growth, the latter have a spontaneous correction potential of 20–30°, whereas self-correction in the frontal plane of up to 6° can be achieved. However, rotational malalignment has a very low self-correction potential. Most of the fractures need additional internal fixation.

In Salter I and II fractures, percutaneous fixation with Kirschner wires may be sufficient. Dislocated Salter III and IV fractures need open reduction and internal fixation. Most cases need additional plaster immobilization for 4–6 weeks. They need to be followed up until the end of the growth period. Fractures of the proximal tibial physis are rarer. The principles of fracture classification and treatment are comparable to the fractures of the distal femoral physis.

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23

Management of Cartilage Injuries in Handball

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23.1 Introduction

The sport of handball has been continuously evolving over the past decades. The game involves many complex sports actions such as sprinting, direction changes, jumping and many acceleration-deceleration actions. Handball also involves frequent and intense contact which adds an unpredicted element to each action.

Knee injuries are often caused by traumatic events [1] but with catastrophic consequences for handball players due to its severity (e.g. ligament or meniscal tears) and long lay-off time [2, 3]. Knee injuries incidence is reportedly to be around 11% for either male or female players [4]. During the 24th Men's Handball World Championship 2015 in Qatar, the knee was one of the most common injured joint, accounting 15% of all injuries [5].

Along with the development of more complex handball tactics, there has been an increasing game frequency and intensity. At the elite level, in which handball players compete for their both their club and national team, the annual number of games can be well over 70 matches, with shorter rest periods between games [4]. This fact has increased the physical and psychological load imposed to the players, which often results in sports-related damage to the knee structures, including articular cartilage injuries. These articular cartilage injuries are often caused by the forceful and repetitive mechanical stresses on the knee joint that occur during handball play [6, 7].

At the elite level in handball, the financial consequences of each injury are very high, contributing additional complex factors to management decision-making for health-care professionals who are involved in the player's recovery. While recreational handball players may seek symptom relief, joint functionality restoration and return to some level of sports participation, professional players will envision the return to their previous level of competition as fast as possible. Hence, the rehabilitation clinical reasoning must be performed taking into account important factors such as the player's age, level of competition, timing within the season and career status (i.e. contract or free agent player or early- versus late-phase career) [8].

Articular cartilage does not have vascular and nerve supply, which has important limitations in its potential capacity to heal [9–11]. Thus, the long-term reestablishment of the articular cartilage surface is still a major challenge for orthopaedic surgeons and scientists, and the handball player may never return to his previous level of competition, and this may lead to an early end of career.

23.2 Epidemiology

Articular cartilage injuries have been reported to be more prevalent in athletic populations than in the general population [8, 12–15].

Flanigan et al. [14] in a systematic review reported the prevalence of knee articular cartilage injuries in a cohort of 931 athletes from different sports (± 33 years old). Overall, 79% of the players were male, and 40% played at a professional level. A total of 883 full-thickness chondral defects were recorded in 355 athletes (94% had more than one chondral defect). The articular cartilage injuries were homogeneously distributed between the femoral condyles (35%), the patellofemoral joint (37%) and the tibial plateaus (25%).

Scientific literature in knee articular cartilage injuries in handball is scarce. Giroto et al. [1] followed 21 Brazilian elite handball teams (n = 339) for a period of 7 months and registered the sport injuries incidence. Overall, they reported 52 (17%) knee injuries and 9 (4%) meniscal/cartilage traumatic injuries. On the other hand, Røtterud et al. [16] analysed data from the Swedish and Norwegian National Knee Ligament Registry (n = 15,783) including a total of 1392 handball players. They found that after anterior cruciate ligament (ACL) reconstruction, 74 handball players (around 5%) had developed full-thickness articular cartilage lesions in their knees (International Cartilage Repair Society—ICRS grades 3–4). Accounting for the entire sample, the authors found that there was an odds ratio (OR) of 1.006 (95% confidence intervals—95% CI, 1.005–1.008) of developing full-thickness cartilage lesion for each month that elapsed from time of injury until surgery. Previous knee surgery and increasing age were also two independent risk factors for developing full-thickness knee cartilage injuries. Considering the male handball players operated within 1 year from injury, there was twofold higher probability of developing full-thickness knee cartilage lesions when compared to football players (OR = 2.36, 95% CI 1.33–4.19). Within the same line, Granan et al. [17] analysed data from the Norwegian National Knee Ligament Registry and Kaiser Permanente ACL reconstruction Registry (USA) comprising a total of 17,063 ACL-reconstructed patients, including 1548 handball players. At the time of primary ACL reconstruction, the handball player cohort displayed 315 knee cartilage injuries (20%). Compared to football players, these had similar probability of developing knee articular cartilage injuries (OR = 0.99, 95% CI 0.84–1.16).

23.3 Treatment

The treatment of articular cartilage injuries in athletes, in general, and handball players, in particular, embodies complex decision-making which may be influenced by a myriad of factors [18]. The objective is to provide durable cartilage restoration to resist the elevated joint mechanical stresses which the players' knees are exposed to during their handball activities [8]. Although the ultimate goal is to provide hyaline cartilage, current treatments may aim to restore the physiological properties of entire osteochondral unit; however, they are not able to achieve a native hyaline cartilage tissue. Nevertheless, it is possible to obtain hyaline-like cartilage or fibrocartilage that is posteriorly integrated within the adjacent cartilage and underlying bone.

23.3.1 Nonoperative Treatment

Nonoperative treatment of knee articular cartilage lesions in handball players may be more applicable in small and superficial focal chondral lesion in early stages. The timing of injury/diagnosis during the season may also be a contributing factor to treatment plan and decision-making. Handball players with more advanced/severe chondral or osteochondral damage who choose to try and proceed playing throughout the rest of the season may choose nonoperative treatment at first stage, to enable this choice. Nonoperative treatment options include chondroprotective pharmacotherapy—oral supplements (glucosamines, chondroitin, diacerein) and injectable therapies (hyaluronic acid, platelet-rich plasma, mesenchymal stem cells and gene therapy) – nonsteroidal anti-inflammatory medication, physiotherapy and hydrotherapy [19–21]. Preliminary results from a pilot prospective study on the efficacy of hyaluronic acid derivatives reported promising subjective clinical and functional improvements in professional football players [22]. Moreover, another study showed significant clinical improvement after biologic therapies (hyaluronic acid and platelet-rich plasma) in end-career professional football players [23]. Despite the symptom relief reported, high-level studies are still lacking to support the use of these therapies for focal articular cartilage lesions in high-level athletes.

23.3.2 Operative Treatment

Currently, several surgical methods are available to approach knee articular cartilage injuries in the handball player. These include reconstructive techniques—mosaicplasty, osteochondral autograft transplantation (OAT) or osteochondral allograft transplantation – and reparative techniques, microfracture, autologous chondrocyte implantation (ACI) and matrix-induced autologous chondrocyte implantation (MACI) [8, 10, 24, 25]. More recently, new biological cartilage restoration techniques have emerged as potential solutions; however, consistent clinical outcomes in athletes are not available yet.

Despite the large variety of current available surgical techniques for treating knee chondral or osteochondral defects, there is no consensus with regard to which is the best and more reliable technique. A recent Cochrane systematic review [26] based on randomized controlled trials of surgical interventions (microfracture, drilling, mosaicplasty and allograft transplantation) for treating isolated cartilage defects of the knee in adults reported that there was insufficient evidence to conclude on the relative effects of mosaicplasty against microfracture procedures, as recurrence of symptoms occurred in both procedures. In a recent meta-analysis comprising of level 1 studies [27] comparing marrow stimulation, ACI and OAT procedures found that there was no significant difference between these techniques in improving function and pain at 2-year follow-up. In a network meta-analysis comparing different cartilage restoration techniques (microfracture, augmented microfracture, ACI with a periosteal or collagen patch, MACI, osteochondral allograft or osteochondral autograft mosaicplasty), it was found that the various cartilage procedures were similar regarding the reoperation rates and functional and clinical outcomes at 2 years. When considering all the measures evaluated (reoperation, Tegner and Lysholm scores, the presence of hyaline cartilage on postoperative biopsy and graft hypertrophy), the authors ranked the second-generation ACI as the best treatment, followed by OATS and MACI techniques [28].

Microfracture has been the most commonly utilized treatment in high-level athletes with the belief that it provides a safe option that will result in a faster return to competition. However, microfracture seems to have higher clinical deterioration overtime and, subsequently, lower clinical durability compared to OAT and ACI procedures [25, 29]. Conversely, the ACI technique (first generation) seems to be the least cost-effective procedure, while microfracture was the most cost-effective procedure [30].

Treatment of articular cartilage injuries in the athletic population must be individualized while considering the defect's characteristics as well as the athlete's needs and surgeon's preferences. Evidence-based treatment of articular cartilage injuries is mainly based on the defect's size and involvement of the entire osteochondral unit [31]. In this sense, larger articular cartilage defects (>2 cm^2) would benefit from ACI/MACI techniques as they provide higher clinical and functional outcomes [32]. Nonetheless, there are other important factors that should be taken into account when considering high-level athletes, such as timing within the season and player's career status. Moreover, the timing of surgery from injury is an important factor, and it has been established that performing the surgery within 1 year from the injury increases the likelihood of returning to sports by three- to fivefold [33–37] while decreasing the risk of further cartilage injury and development of knee osteoarthritis [11, 34, 36–41].

In light of the many clinical management approaches available, several clinical treatment algorithms have been developed [10, 31, 40, 42–45]. In-season and early career articular cartilage injuries frequently require a faster management, because the player requires a faster return to competition. In this sense, when the player has smaller defects (<2 cm^2), the surgeon may consider nonoperative treatment or even a surgical debridement or microfracture/OAT. If the defect is larger than 2 cm^2, it may be opted to simply debride the articular cartilage defect, providing the player pain relief to withstand the rest of the season while collecting cartilage biopsy during the surgery to perform a more durable procedure (ACI/MACI) in the off-season period. Within the same line, if the handball player is towards his late-career, the microfracture/OATS procedures may provide a fast pain relief to play the rest of his career and perform an ACI/MACI procedure when the player retires [24].

We propose a clinical treatment algorithm for articular cartilage injuries in professional handball players (Fig. 23.1), adapted from the algorithm developed by Bekkers et al. [24].

Microfracture

Microfracture has been frequently used as first-line treatment as it provides a faster return to competition and good short-term outcomes [18, 46]. Nevertheless, clinical outcomes deteriorate at long term, even necessitating revision surgery in some cases [31].

The technique involves micro-perforation of the subchondral bone plate after the defect is properly debrided. These micro-perforations provoke

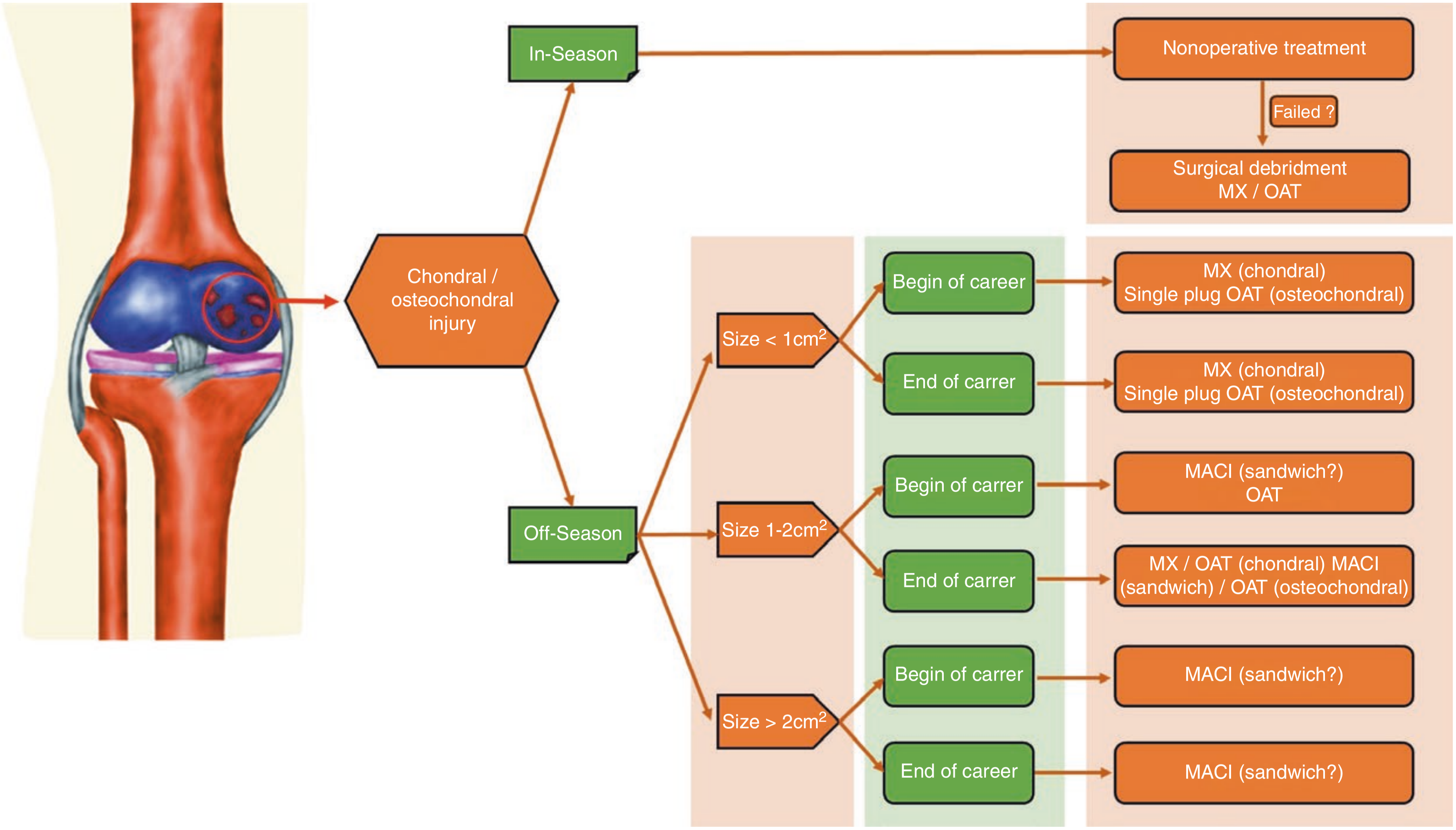

Fig. 23.1 Clinical treatment algorithm for articular cartilage injuries in professional handball players

the release of medullar bleeding which contains marrow elements (including mesenchymal stem cells, growth factors and other healing proteins). The cellular differentiation occurs, and a stable bone marrow clot is formed to fill the chondral defect, providing an enriched environment for new tissue formation [47–50]. The micro-perforations should be perpendicular to the defect's surface, comprising a depth of 3–4 mm and separated by 3–4 mm [51]. The clot eventually matures into a firm and smooth repaired tissue (fibrocartilage) yielding mechanical properties that, due to its softness and decreased capability to withstand the joint shear stresses, are not entirely prepared to withstand the high loading demands of these athletes and may eventually fail [52–54]. As a consequence, enhanced microfracture techniques – combination of the microfracture procedure with orthobiologic products—have been developed to achieve better clinical and functional outcomes [53, 55].

Microfracture has been shown to provide good clinical results in young patients with small defects at the short-term follow-up [46, 56, 57]. Nevertheless, potential early development of knee osteoarthritis and treatment failure at later stages – 5–10 years follow-up must be taken into account [56]. Results in professional athletes also show good clinical results in smaller lesions, which also deteriorate overtime [33, 39, 58–60]. Overall, good short-term clinical outcomes have been achieved with enhanced microfracture techniques [53, 61–66]. When comparing conventional microfracture with enhanced microfracture techniques, the scientific literature is inconclusive [8, 67]. More high-level studies with long-term follow-up are required to assess the effectiveness of enhanced microfracture techniques and compare with the remaining available articular cartilage surgical techniques [55].

Osteochondral Autologous Transfer Surgery (OATS)

The OATS technique consists of transfer/transplantation of an autologous or allogenic hyaline osteochondral plug (usually from the patient's non-weight-bearing area) into the articular cartilage defect. This technique has the advantage of providing a stable and size-matched hyaline osteochondral graft to fill the defect. In smaller defects, a single plug may be enough; however, for larger defects, it can be used the mega-OATS technique (transferring a larger osteochondral plug) [68, 69], but the mosaicplasty technique may be more adequate as it is able to fill the defect with multiple cylinders (osteochondral plugs) [47, 48].

Limited graft availability and donor-site morbidity are shortcomings that have been reported in the literature for the OATS technique. Donor-site morbidity prevalence is reported to be 5.9%, and the most common donor-site morbidity complaints reported comprised patellofemoral disturbances (22%), crepitation (31%) and post-operative effusion (9%) [70].

To overcome these shortcomings, it has been suggested to use the upper tibio-femoral joint as a potential donor site for osteochondral harvesting. The upper tibiofibular joint allows the possibility to harvest up to 5 cm^2 of osteochondral graft, and transplanting up to six plugs of 6 mm diameter without additional iatrogenic complications has been shown to provide good clinical outcomes [71].

The use of mosaicplasty and OATS techniques for treating knee articular cartilage defects has shown improved postoperative clinical outcomes [72, 73] which are maintained overtime [74]. Moreover, it has shown an advantage over the microfracture technique in younger patients with small chondral lesions [72].

In cases of osteochondritis dissecans, limited graft availability or very large defects, the osteochondral allograft transplantation has been considered as a viable option [75–77]. Nevertheless, concern regarding failure must be taken into account [78, 79].

Autologous Chondrocyte Implantation (ACI) and Matrix-Induced Autologous Chondrocyte Implantation (MACI)

The ACI technique is a two-stage procedure involving the implantation of autologous chondrocyte cells into the articular cartilage defect [47, 48, 80, 81]. It is mainly indicated for the treatment of medium to large-sized, full-thickness articular cartilage defects.

First stage involves the arthroscopic procedure to perform the harvest (200 mg) of healthy articular cartilage from the patient's non-weight-bearing areas, which would then be isolated and expanded in laboratory setting. Once the cultured cells have grown, it is possible to proceed with the second stage, involving placement of a size-matched patch into the defect, with fibrin placed around the defect's edges, and the patch is sutured for stabilization. The cultured chondrocyte cells are inserted and suspended into the upper side of the defect, and the access is closed with fine reabsorbable sutures and fibrin glue [82].

Due to the high-cost associated with the technique and the invasiveness of the procedure, it is often a second-line treatment for defects smaller than 2 cm^2 in which it is generally reserved for revision of previously failed cartilage repair. However, for larger defects, it can be used as a primary procedure due to the lowered efficacy of other procedures, such as microfracture or OATS. Though, it is still not able to consistently achieve hyaline-like cartilage and some patients may still develop fibrocartilage [83, 84]. One of the advantages of this procedure is its' ability to provide a more longstanding repaired articular cartilage tissue.

Long-term follow-up (10–20 years) showed good long-term clinical and functional outcomes [37, 41, 85, 86]. As the technique has evolved overtime, improved results have been achieved with the second-generation ACI technique [87].

More recently, the third-generation ACI technique (MACI) is an attractive alternative which involves seeding the chondrocytes cells into a biodegradable scaffold which is later implanted into the articular cartilage defect [47, 48]. This new generation technique avoids the morbidity related to the autologous cartilage harvesting and two surgical procedures by obtaining allogenic tissue or autologous stem cells for cartilage regeneration [88]. In addition, the MACI sandwich technique, which involves the implantation of a two-membrane custom-made (bottom membrane facing up and top membrane facing down), has the advantage of reducing the operation time and exposure [47]. The reported short- to mid-term outcomes show promising results of this technique in articular cartilage injuries of the knee joint [89–91].

23.3.3 Treatment of Associated Lesions

Knee articular cartilage injuries are often associated with other knee injuries including ligament and meniscus deficiency. These associated lesions should be treated concomitantly [21, 42, 92–94] having the advantage of avoiding the need for a second-stage surgical intervention, improving the overall cartilage repair and without negatively influencing the return to sports [34, 36–38].

The most common procedures in association with knee articular cartilage surgeries are meniscal resection or repair, ACL and collateral ligaments reconstruction, high tibial osteotomy and tibial tubercle osteotomy [8, 14]. However, new evidence from a double-blind randomized controlled trial investigated the effect of debridement of unstable chondral lesions (Outerbridge grades II–IV) on pain in patients undergoing arthroscopic partial meniscectomy (age over 30 years) [95]. At 1 year after arthroscopic partial meniscectomy, there were no significant differences on pain, function, symptoms, activity, quality of life or general health between the group of patients randomized to debridement of unstable chondral lesions or the group that left the chondral lesions in situ, suggesting there is no additional benefit by debriding unstable chondral lesions encountered during arthroscopic partial meniscectomy.

23.4 Postoperative Rehabilitation and Return to Play Guidelines

The *post*operative rehabilitation is one major keystone for the player to return as fast and as safe as possible to pre-injury-level competition, as well as prevent reinjury and long-term sequelae [24, 96]. This statement is confined within the limits of the biologic healing process and timescale and in this context. Thus, rehabilitation as the main goal provides the joint with the optimal mechanical environment for tissue adaptation and remodelling [97]. The rehabilitation progression should always take into account the tissue biology related to the surgical technique performed, characteristics of the defect, patient's symptomatology and level of competition. The location of the defect has important implications in the postoperative rehabilitation. In this sense, trochlear defects may require weight-bearing and range of movement progression adjustments [98]. In addition, in cases where a concomitant injury was also surgically treated, caution should be taken towards a slower rehabilitation progression [99, 100]. The postoperative rehabilitation of knee articular cartilage repair is usually based on three major phases, with progression based on objective criteria. In all stages, it is important for the physiotherapist to monitor the athlete's knee symptomatology (especially pain and swelling) once it may be indicative of overloading [97]. Hence, rehabilitation should be a stepwise and individualized programme according to athlete's specific demands and surgical technique specifics, with a criteria-based progression through the different phases (Fig. 23.2).

Fact Box

- The first phase of the rehabilitation (graft integration and stimulation) focuses on joint protection (load and range of motion) and progressive knee function.
- The second phase of rehabilitation (extracellular matrix production and cartilage organization) provides progressive loading to the knee joint while coupling incremental knee function capabilities with the introduction of sport-specific drills.
- The third phase of rehabilitation (remodelling and maturation of the repaired cartilage tissue) focuses on late stages of physical and motor reconditioning aiming at return to sports.

The first rehabilitation phase is focused in the progressive restoration of the knee range of movement and weight-bearing, as well as increases muscle activity and strength and restores neuromuscular control while controlling knee pain and swelling through the process [97, 98, 101–105]. In the reparative surgical techniques (ACI/MACI/microfracture), the physiotherapist must avoid mechanical overloading of the repaired tissue which may hinder the repaired tissue integration [106, 107]. Although accelerated rehabilitation protocols have been proposed, with full weight-bearing at 6–8 weeks [108, 109], further high-quality research is warranted [110]. At early stages, swimming pool rehabilitation (as soon as the surgical wounds' healing allows) provides a low-impact environment, allowing performance of rehabilitation exercises under partial weight-bearing conditions and decreased axial load conditions with gradual progression. Another option allowing partial and controlled weight-bearing activities is presented with antigravity treadmills (e.g. Alter-G®, Fremont, California, USA). Such treadmills enable measurable partial weight-bearing control ranging from 20 to 80% of the body weight. Hambly et al. [18] have suggested a return to running programme on antigravity treadmill following microfracture procedure at the knee. To progress into the next phase, the following are required: full passive knee range of motion, minimal knee pain and effusion and restoration of muscle activation and normal gait [97, 101].

The goal for the second phase of rehabilitation is to manage knee mechanical loading and increase neuromuscular control to allow pain-free running, without effusion or locking. At this stage slow restoration of sport-specific movement patterns is commenced [97, 101]. Knee rehabilitation exercises in combination with upper limb ball drills should be implemented at this stage (Fig. 23.3). Progression to the following phase is dependent on the player's capability to run at 8 km/h for more than 15 min, without pain or joint effusion. Additionally, one-legged hop tests and isokinetic performance with side-to-side difference below 20%, as well as patient-reported outcomes measures greater than 90% have been suggested as important measures to achieve [97,

Fig. 23.2 Criteria-based stepwise clinical progression, from injury to return to play

Fig. 23.3 Representation of a handball player performing a single-leg balance exercise while combining with an upper limb strength/coordination exercise (with a kettlebell). Drills incorporating handball-specific movements, such as catching and throwing the ball, may be implemented

101]. When utilizing such measures, it is important to compare the hop tests and isokinetic performance with the estimated capacity of the uninvolved limb at the preoperative stage (or, if available, with preseason evaluation data), in order not to overestimate the postoperative knee function and goals [111, 112].

The third and final rehabilitation phase aims to re-establish the pre-injury level of sports performance, with minimal risk of reinjury. At this stage on-field rehabilitation exercises are implemented aiming to restore residual physical and psychological impairments related to muscle strength/force and coordination, neuromuscular control, speed and endurance performance, metabolic capacity, self-efficacy and sport-specific movement patterns [32, 97]. During the on-field rehabilitation, sport-specific skills replicating the complex interactions of sports are implemented, including high-speed pivoting and cutting activities, plyometrics and acceleration and deceleration drills [32, 67, 97]. Additionally, this rehabilitation stage is important to allow the player to gain self-confidence and sport-specific self-efficacy to the athlete, which will have a pivotal role in the return to competition at first stage and eventually to pre-injury level [97].

Although returning to competition at the same level as fast as possible represents perhaps the most important and desired outcome for the player and his team, clearance for return to sport should be based on objective criteria to avoid secondary injuries and decrease the risk of overloading the repaired tissue [34, 96, 113]. Therefore, return to competition criteria include the completion of the sport-specific exercises/preparation as well as one-on-one opposed practice (with progression of contact exercises) of sport-specific skills, without knee pain or effusion. Moreover, at the completion of this phase, hop tests and isokinetic performance side-to-side differences should be below 10%, and patient-reported outcome measures should be greater than 90%. In addition, it is to evaluate and address any signs of kinesiophobia or fear of reinjury [97, 101].

23.5 Return to Play Outcomes

Regarding articular cartilage lesions of the knee in athletic populations, the scientific literature reports that around 75% of the players expect to return to play following OAT/mosaicplasty, microfracture and ACI surgical techniques [38, 114, 115]. Considering data from three systematic reviews of return to play in athletic populations [38, 114, 115], the return to play rates seem to be higher after autologous and allogenic chondrocyte transplantation (Table 23.1). Nonetheless, when focusing the return to play at the pre-injury level, the rates among the different surgical techniques are similar (range, 68–79%). On the other hand, the time to return to play displayed considerable differences according to the surgical technique used. The OAT procedure allows a faster return to the competition (range, 5.2–7.1 months), followed by the microfracture (range, 7–9.1 months) and allogenic chondrocyte transplantation (range, 9.2–9.6 months). The ACI procedure, due to the more conservative rehabilitation restrictions, has the longest time to return to play (range, 11.8–18 months).

The reasons athletes return to sports and continue to participate at their pre-injury level are definitely multifactorial. Several patient- and defect-specific factors seem to influence the outcomes after knee articular cartilage surgery. Playing at a higher level (when compared to recreational players), younger age, shorter preoperative period of time with symptoms (<12 months) and less previous knee surgeries have been reported as positive prognostic factors for improved clinical and functional outcomes and faster return to sports [38, 114]. Patients with non-traumatic, multifocal lesions have showed worse outcomes [21]. Additionally, smaller defect sizes (< 2 cm^2) and more superficial lesions (chondral vs osteochondral) were associated with a greater likelihood to return to competition [38]. Concomitant procedures such as meniscectomy, ACL reconstruction and osteotomy seem to do not negatively affect outcome after ACI and, in fact, were associated with better outcomes after OATS and microfracture.

Table 23.1 Return to sports (%) and (months) following articular cartilage surgery in an athletic population, based on results of systematic reviews

		Surgical technique			
Outcome	Study	MF	OAT	OCA	ACI
RTP rate	Campbell et al. [114]	75%	89%	88%	84%
	Krych et al. [115]	58%	93%	88%	82%
	Mithoefer et al. [38]	66%	91%	NR	67%
At pre-injury level	Campbell et al. [114]	69%	70%	79%	76%
	Mithoefer et al. [38]	68%	70%	NR	71%
Time to RTP	Campbell et al. [114]	8.6 mo.	7.1 mo.	9.6 mo.	16 mo.
	Krych et al. [115]	9.1 mo.	5.2 mo.	9.2 mo.	11.8 mo.
	Mithoefer et al. [38]	7 mo.	7 mo.	NR	18 mo.

MF microfracture, *OAT* osteochondral autologous transfer, *OCA* osteochondral allograft transplantation, *ACI* autologous chondrocyte implantation, *NR* nonreported, *mo* months, *RTP* return to play

Fact Box

Surgical technique decision may vary depending on the player's age, defect size, level of competition, career status and time during the season.

Surgical techniques provide similar return to play rate to pre-injury level. The OAT/mosaicplasty and microfracture allow a faster return to sports, however with lower durability. ACI/MACI results in a delayed return to sports; however it provides a durable and higher quality repaired tissue.

Large articular cartilage defects (>2 cm^2) benefit the most from ACI/MACI procedures, while in smaller defects (<2 cm^2) nonoperative treatment, surgical debridement or microfracture/OAT procedures appear to be the first choice.

The surgical procedures described above allow most of the athletes to return to their pre-injury level and prolong their career. However, to what extent their career is prolonged requires further research. Additionally, the incidence of new cartilage lesions, meniscal lesions and development of knee OA following cartilage surgery in handball players also requires further investigation.

23.6 Take-Home Message

The ultimate goal for the handball player is to return to play at the pre-injury sports activity level as fast and as safe as possible.

The clinical decision-making regarding the surgical technique and rehabilitation procedure must be individualized according to the defect characteristics (size and depth), as well as according to the individual characteristics (age, level of competition, career status and time within the season).

It is expectable that around 75% of the players will return to competition and that the majority will return to the same level of play. Nonetheless, depending on the player's current career status and his personal preferences, with regard to medium-large defects, it may be opted for an approach which provides a faster return to competition (OATS) or for an approach that provides a more durable repair (ACI/MACI).

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Foot and Ankle Problems in Handball

24

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24.1 Introduction

Currently, handball can be considered as one of the most popular sports in Europe, played by men, women, and children of all ages [1]. Worldwide, handball is played by approximately 20 million athletes, registered in 800,000 teams and represented by the International Handball Federation (IHF) that officially lists +150 member federations [2]. Team handball has been an Olympic sport since 1972, and in Europe, it is one of the most popular team sports after football, volleyball, and basketball.

Handball is one of the top four athletic sports that suffers from the highest risk for injury [3] due to player collisions and the overall explosive nature of the game that can lead to musculoskeletal injuries [4].

The incidence of handball injuries reaches up to 40.7 injuries per 1000 h of match or 3.4 injuries per 1000 h of practice [5], and statistics show that 50% of game injuries occur in an offensive situation, 26% in defense, and 10% during the warm-up phase before a game. In 14% no exact origin can be found [6].

The handballer's foot/ankle has therefore to adapt to the specific sport features such as the arena surface on which the game is performed. The foot/ankle has to undergo atmospheric constraints and adapt to the different energy-absorbing surfaces of these synthetic terrains [7]. The specific entities of the handball sports shoe also need to be modified in this regard. Although the classic foot/ankle lesions—which are encountered in handball—are mainly linked with trauma, shoes, the ambient environment, and the relative hygiene of some players can be as important determinants for problems also [7, 8].

24.2 Mechanism of Ankle Injury

The "jump shot" is the most accomplished goal shot technique during which ankle injuries commonly occur [9] (Figs. 24.1, 24.4, 24.14).

Fig. 24.1 Image of a classic attacking pose by a left hand sided handball player

The ankle joint complex (AJC) is generally differentiated between the talocrural joint (TCJ) and the subtalar joint (STJ). The TCJ rotates around a sagittal axis known as plantar flexion and dorsiflexion [10].

The STJ is considered to be one functional unit of multiple segments (subtalar, talonavicular, calcaneocuboidal), allowing for an axial axis motion known as inversion and eversion. At the subtalar joint, *inversion* is coupled with plantar flexion, adduction, and supination, and *eversion* is coupled with dorsiflexion, abduction, and pronation [11].

Fig. 24.2 Antero-posterior view X-ray depicting a handball-induced phalangeal hallux fracture

The lateral ankle ligaments and especially the anterior talofibular ligament are one of the most injured structures due to inversion sprains in handball [12, 13].

24.3 Handball Injury Analysis

The most common types of injuries are sprains (46%), strains (26%), fractures (10%) (Fig. 24.2), contusions (6.6%), and dislocations (5.5%) (Fig. 24.3a, b), while 54% of all injuries occur at the lower extremity and 61% at their dominant side [14].

Sprains occur most commonly over the ankle, the knee, the fingers, the wrist, and the acromioclavicular joint. Mainly due to the explosive nature of the handball game (Figs. 24.4, 24.14), strains occur most commonly over the muscles of the lower extremity (thigh and calf). Typically, fractures occur to the nose, the fingers, the metacarpals, the metatar-

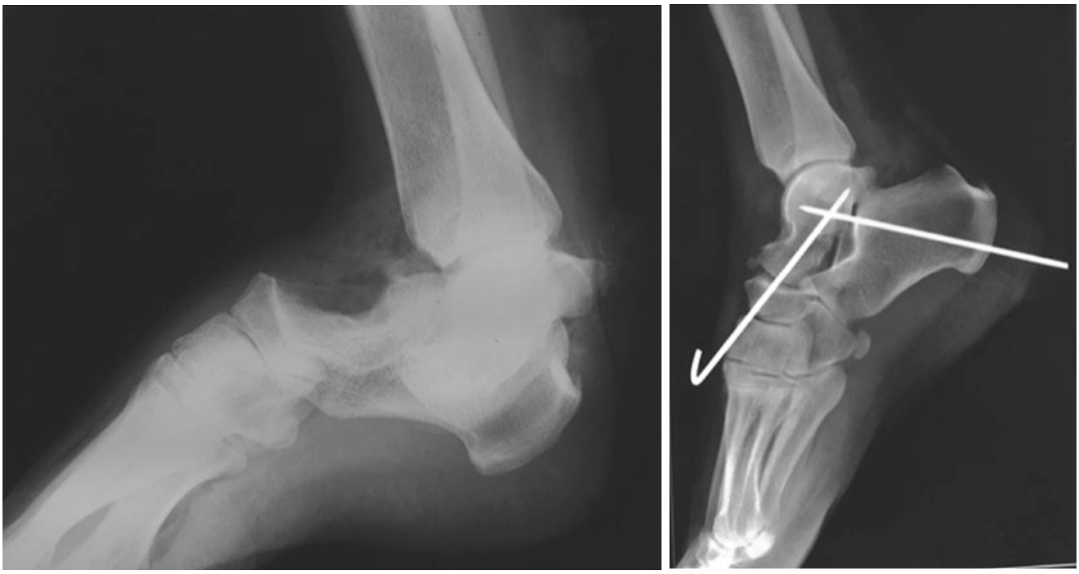

Fig. 24.3 Lateral view X-ray depicting a handball-induced talocalcaneal luxation with reduction (**a**) and initial K-wire fixation (**b**)

Fig. 24.4 Image depicting several dynamic postural positions of the handball player during gameplay

sals, and the forearm. Dislocations occur to the shoulder, the metacarpophalangeal joint of the thumb, and the proximal interphalangeal joint of the fifth finger [15].

There is no correlation between the timing of the season and the injury types sustained, since injuries (specifically sprains) occur as much at the beginning as at the end of season [16].

24.3.1 Overuse Symptoms

Most foot/ankle injuries in handball are benign injuries with 66% being due to overuse and fatigue, and they are equally distributed among player positions/types. However, the rate of severe injuries in regional league handball competitions is higher. Wing players have the highest rate of serious injuries, followed by backcourt players, goalkeepers, and line players. The ratio of upper versus lower extremity injuries is different with respect to the player type accounting for 0.33 for goalkeepers, 0.54 for line players, 0.8 for wing players, and 0.9 for backcourt players [6, 14–16].

24.3.2 Prevention

Up to 93% of elite handball players use some sort of protective support while playing/training [1]. This consists of high-top athletic shoes, knee or elbow protectors, ankle orthoses and inlays, and knee braces. And they seem to be mostly used by goalkeepers and line players. Ankle protectors (orthoses, tape, high-top shoes) are used by 45% of the goalkeepers (high-top shoes in 92%), 41% of backcourt players (high-top shoes in 46%, orthoses or tape), 32% of wing players, and 29% of line players. There is a significant correlation between the use of ankle bracing and previous injury sustained, and over 30% of players even injured their ankle while wearing protective bracing [6, 17].

Fifty-seven percent of all protective material used in handball is aimed to prevention reinjury or treat chronic symptoms. A significant correlation can be shown between prior ankle injuries and the use of ankle bracing in handball. They are mostly used by line and backcourt handball players because of their repeated pivoting movements and explosive jumps in gameplay (Fig. 24.4).

Most sprains occur when landing from a jump in plantar flexion. This position makes the ankle prone to ligament injury due to the orientation of the anterior talofibular ligament fibers [18].

24.3.3 Comparison with Other Sports

As in football, game injury incidence in handball is significantly higher than during practice, and this can be explained by the intensity and contact collisions during gameplay. However, a significantly higher injury incidence is seen in the lower-level competitions. This is comparable with the findings of Ekstrand et al., who noted a reduction of injuries with increasing practice hours in football [19]. This can probably be attributed to an improved coordination, better oxygen uptake, greater strength, and more skill. The latter might be the main explanation of a lower practice injury incidence in comparative studies with children and adolescents [20].

In high-level competitions, the amount of game injuries seems higher, but—although such a tendency has already been demonstrated in other sports [19, 20] and several authors found similar results for handball injuries [21]—there is still a lack of available handball-related epidemiological data. In a longitudinal study on +1800 school children, there was a decreased injury rate with increased performance level in several sports, especially between national and regional competitions [22]. The authors hypothesize that high-level players are more skilled and less prone to injury. Further studies, comparing professional and nonprofessional incidence rates, are needed to answer this question.

In elite handball, wing players seem to be most at risk for injury, before line players, goalkeepers, and backcourt players. Wing players also have the highest severity rate of injury. Their motion and stress patterns show more variation compared to other handball player positions: explosive jumps and falls, a high number of contact situations with opposing players, and involvement in counterattacks increase the injury rate in these players. However, other studies present data that backcourt players are more at risk [6].

To our knowledge there are only two studies comparing handball injury rates directly to other sports injury rates. Handball injuries occur less frequent than in volleyball (4.3 versus 6.7 injuries per 1000 practice hours) and basketball (14 versus 23 injuries per 1000 game hours) in a population of school children [22]. Also there is no statistically significant difference in injury incidence between handball, soccer, and basketball in an adolescent population [20]. A similar game injury incidence is reported in soccer (16.9 per 1000 game hours) but with a much higher practice injury incidence (7.6 per 1000 practice hours) [20].

Whereas several authors found an equal distribution between upper and lower extremity injuries, there is clearly a predominance of lower extremity injuries in handball [6]. Among the 54% of lower extremity injuries, knee injuries are most frequent, followed by ankle injuries, and these findings are consistent with those of previous studies. Knee injuries have the highest injury risk in the high-level group but that ankle injuries accounted for the highest injury risk in the lower-level group. Three main causes are reported for these frequent lower extremity injuries: a lack of coordination due to increased fatigue with a continuously growing number of games and practice sessions; opposing players' influence on a relatively small area, which is inherent to the game; and the rubber floor/shoe surface [6–8, 14–17].

24.4 The Handballer's Shoe

Handball and its ballistic conduct of jumping and landing require a great freedom of the tibiocrural joint and a great stability in the subtalar and midfoot joints.

Thus, the modern shoe needs to be high necked, and the hindfoot stabilizers shouldn't stop at the crop of the malleolar edges. The challenge remains that the shoe needs to protect the ligaments and tendons but also allow for necessary foot/ankle mobility that the sport requires [7].

This explains the facilitation of abnormal movements (hammer/anvil), causing degenerative ankle lesions and painful wounds and contusions at the periosteum that eventually can lead to significant healing time [8].

Also, the Chopart joint area and its surrounding ligaments of the foot are well known to suffer from this repetitive jumping, landing and torsional loading in handball [6].

In summary, the shoe has to take into account classic handball-related foot problems such as subungual hematomas, overuse syndromes, early joint degeneration, avulsions, stress fractures, and big toe hallux rigidus features.

24.5 Dermatological and Cutaneous Lesions

Precocious disinfecting strategies can prevent chronic foot problems in handball through simple protocols. In order to avoid lymphangitis, adenitis, and cellulitis problems, it's important that young handball players get acquainted with the necessary habits to show all hematomas, wounds, and blisters over the foot to the club's physio or medical doctor immediately after every match or training (Fig. 24.5a–c).

Frequently encountered handball-related foot problems that require specific medical (dermatological) care are:

- Bulbs and blisters
- Ingrown toe nail
- Subungual hematoma
- Plantar warts
- Hyperhidrosis.

24.6 Common Traumatic Foot Injuries in Handball

- **Turf Toe (First Ray Metatarsophalangeal Sprain)**
  - Etiology: injuries to the first metatarsophalangeal joint are commonly encountered in handball players who participate on hard surfaces while wearing flexible shoes. Recent data suggest that turf toe injuries occur more commonly in handball players with an associated decreased MTP motion and an increased hallucal peak pressure [23].
  - Injury mechanism: forced hyperextension of the first metatarsophalangeal joint tears the plantar portion of the capsuloligamentous complex at its origin from the metatarsal head and neck [24] (Fig. 24.6).
  - Clinical and diagnostic examination: a turf toe is a debilitating injury in handball because the hallux is pivotal to a handball player's ability to accelerate and cut. Immediately after trauma, the initial swelling and pain can be minor, but it then worsens over the next 24 h. In addition to the soft tissue injury, there can be a combined presentation of metatarsal head impaction and fractured or unstable bipartite sesamoid [25] (Fig. 24.7a–c).

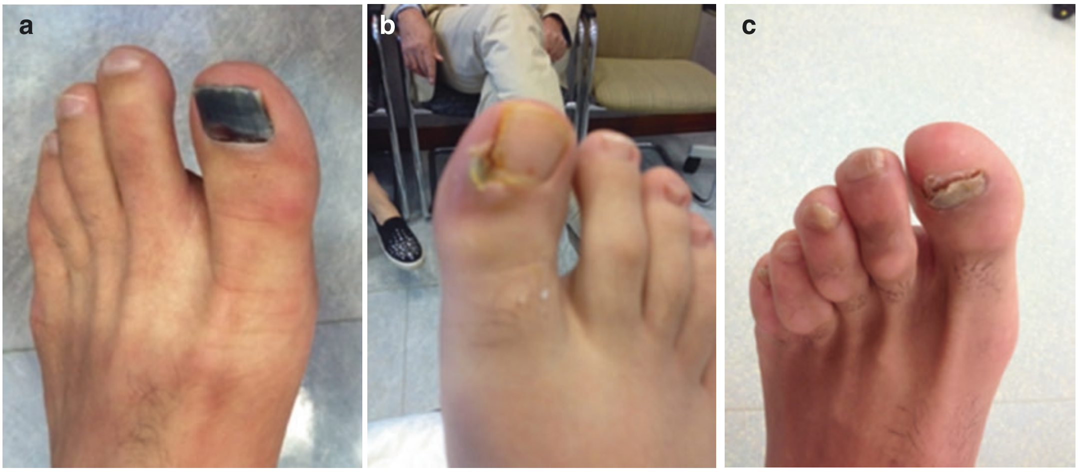

Fig. 24.5 Clinical pictures of common hallux problems in the Handball player: subungual hematoma (**a**), ingrown toenail (**b**), hyperhidrosis (**c**)

  - Treatment strategy: most turf toes can be treated nonoperatively. A tailored handball shoe and an individualized inlay sole—which limits the hyperextension of the first metatarsophalangeal joint—can give adequate support to the soft tissue injury. Nevertheless it's advised to tape the toe for handball training and gameplay. Severe injuries can require temporary restriction from handball and can require the need of protected weightbearing with crutches for several days. Only in case of irreducible dislocation or full rupture of the plantar plate (with sesamoid retraction) a surgical intervention is indicated. These injuries warrant appropriate acute and long-term management to prevent long-term dysfunction [26, 27].

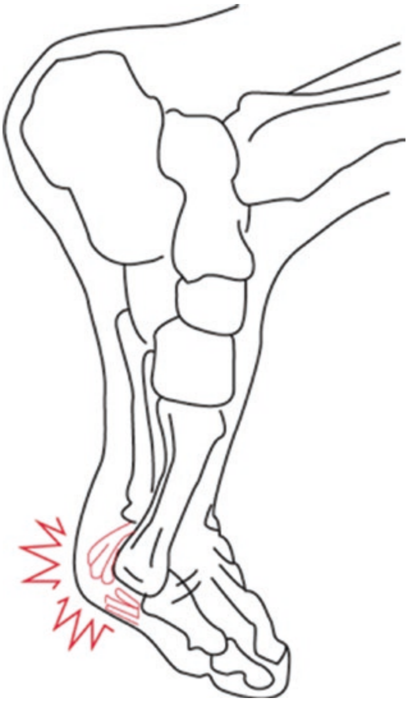

Fig. 24.6 Digital image depicting the turf toe mechanism of injury during Handball

- **Metatarsal Fractures/Tarsometatarsal Dislocations**
  - Injury mechanism: a direct blow or twisting injury with severe foot pain, immediate inability to weightbear, and the need to be substituted are classic presentations of a metatarsal fracture during the initial assessment [28–30].
  - Clinical and diagnostic examination: the foot can rapidly swell up to twice its normal size; there's a localized or global tenderness over the injured areas (in case of additional midfoot/Lisfranc/forefoot injury). A classic X-ray can usually reveal the specific diagnosis.
  - Treatment strategy: a stable metatarsal shaft fracture can be treated with a partial weightbearing boot or a stiff-soled shoe and crutches. In case of a Jones fracture, it's advised to consult your orthopedic surgeon since transverse fractures of the shaft of the fifth metatarsal need individualized treatment, especially when dealing with elite handball players [31] (Fig. 24.8a–c).

The treatment should be based upon the player's needs, and early internal fixation is shown to be frequently indicated in this regard, since it provides stability for reliable healing and lower reinjury rate, allows accelerated rehabilitation, and thus decreases the time lost from handball.

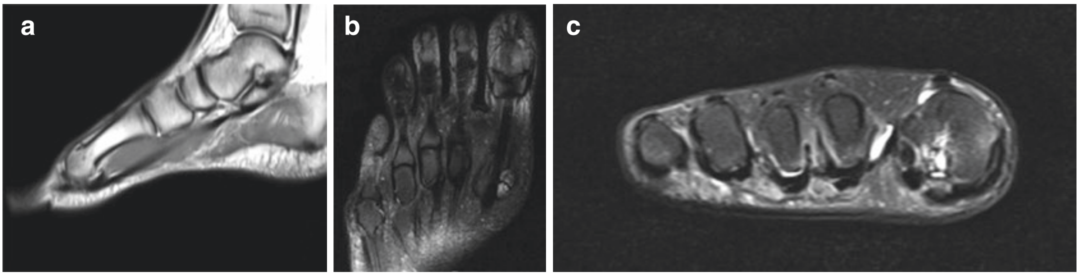

Fig. 24.7 Sagital (**a**), axial (**b**) and coronal (**c**) MRI view of a turf toe injury mechanism during Handball

Fig. 24.8 Antero-posterior view X-ray depicting a handball-induced Torg 1, Torg 2 and Torg 3 metatarsal 5 fracture

Tuberosity fractures of the fifth metatarsal are treated with a boot until the player is asymptomatic, and supportive taping/cuboid pad can be used to relieve the pressure from the fracture site.

Intra-articular fractures (with a displacement of 2 mm or more), an unstable spiral fracture, Lisfranc fracture/dislocation, and the presentation of two or more metatarsal fractures in the foot are usually treated with open reduction and internal surgical fixation [28–31].

- Rehabilitation and return to play: rehabilitation can start upon sufficient fracture healing. Progressive weightbearing activities can be initiated within pain limits. Particularly important exercises are plantar fascia stretching and the strengthening of the intrinsic foot musculature. Full participation toward handball is usually allowed when the fracture healing is complete and the strength and flexibility have returned to approximately 90–95% of the opposite, uninjured foot [28–31].

- **Midfoot Sprains (Lisfranc Injuries)**
  - Etiology: the Lisfranc joint is a complex skeletal and capsuloligamentous structure that provides significant stability while maintaining the transverse arch of the foot. Handball players suffer a much higher rate of midfoot sprains, compared to the general population. They are the second most commonly documented foot injury in handball after injury to the metatarsophalangeal joint and occur in 4% of handball players per year [6, 14–17].
  - Injury mechanism: in contrast with the high-velocity roadside Lisfranc injuries, handball-related midfoot sprains occur by means of an indirect low-velocity force. Most players describe an axial longitudinal

  force sustained, while the foot was plantar flexed and slightly rotated [32].
  - Diagnostic examination: weightbearing radiographs and bone scintigrams are commonly used to diagnose these midfoot sprains. In case of doubt about the stability aspects of the sprain, clinical examination together with contralateral foot X-ray comparisons can be found very helpful.
  - Treatment strategy: the management of stable undisplaced midfoot sprains in handball players is normally successful with nonoperative management. However, the appropriate management of midfoot sprains with diastasis is controversial. Although these sprains represent a true Lisfranc injury, its management can differ from the classic surgical anatomical reduction, that is, the standard treatment for high-velocity Lisfranc injuries. Restoration and maintenance of the anatomic alignment of the Lisfranc joint is the key to appropriate treatment of severe midfoot sprains (Fig. 24.9).
  - Rehabilitation and return to play: midfoot sprains in handball are associated with an acute disability that can require prolonged restriction from competition (up to 3 months although most lesions recover quickly (4–6 weeks) and long-term residual problems are minor) [32, 33].

Fig. 24.9 CT scan image of a Handball-induced midfoot sprain injury mechanism with combined fractures at the base of metatarsal 2 and 3 plantarly

24.7 Common Non-Traumatic Foot Injuries in Handball

- **Stress Fractures**
  - Etiology: repetitive cyclical loading after sudden increase in intensity, frequency, and duration of training usually causes stress fractures over the foot (Fig. 24.10).
  - Clinical and diagnostic examination: the handball player presents with swelling, pain, and localized tenderness over the foot. AP, lateral, and oblique X-rays do not always exclude a stress fracture, and an MRI or bone scan can be indicated to acquire a definitive diagnosis [34, 35] (Fig. 24.11).
  - Treatment strategy: stress fractures in the foot are notoriously known for difficult and

Fig. 24.10 Antero-posterior view X-ray depicting a handball-induced healed subcapital metatarsal 4 left foot stress fracture

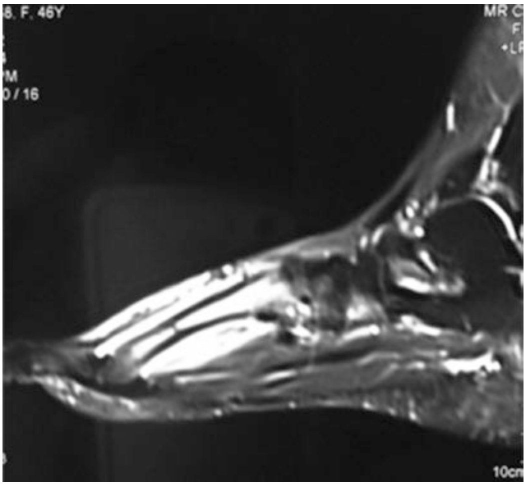

Fig. 24.11 Sagital T2 MRI image depicting an active metatarsal midshaft stress fracture

Fig. 24.12 Antero-posterior view X-ray depicting a bilateral hallux rigidus problem in a Handball player

  slow healing, especially in the areas of the talar neck, the tarsal navicular, and Jones' fifth metatarsal. Boot immobilization, electromagnetic pulse stimulation, and non-weightbearing are started, but surgical fixation (with or without bone grafting and drilling) can be indicated in case of delayed union or displaced fractures.
  - Rehabilitation and return to play: weeks/months of restricted weightbearing are usually needed during the rehabilitation phase. Pool exercises can be started early with further gradual progressive rehabilitation protocols within pain limits to be followed. A handball player with an asymptomatic but incomplete fracture is allowed to regain training after 6 weeks using appropriate protective orthoses (steel shank and arch support) for at least 6 months more. It can take up to 6–9 months though in case of required surgical intervention before the player is allowed to play full throttle again [36].

- **Hallux Rigidus**
  - Etiology and injury mechanism: hallux rigidus is a disabilitating degenerative disease of the first metatarsophalangeal joint. In handball, the disease arises from the repetitive dorsiflexion/jumping of the foot's first row. Together with trauma, systemic arthropathies, hyperpronation, an elevated metatarsal, poor footwear, and an unusually long first metatarsal can also initiate the degenerative changes.
  - Clinical and diagnostic examination: the handball player complains of pain, swelling, and decreased motion over the great toe. The diagnosis is made by X-ray showing joint space narrowing and osteophytes and metatarsal head flattening (Fig. 24.12).

Ankylosis of the joint may also occur but is usually present at a later stage of the disease.

- Treatment strategy: adjustments to the handball shoe/inlays and podiatric modifications (to limit the motion of the first metatarsophalangeal joint) are the initial preferred type of treatment in handball players with hallux rigidus. As an adjuvant to the biomechanical corrections of the handballer's foot made, an oral NSAID or intermediate-acting steroid intra-articular injection can help to relief the synovial joint inflammation. In case of failed conservative treatment, most players are treated surgically with a cheilectomy that removes the dorsal joint impingement of bone and soft tissue. Other surgical options available are dorsiflexion osteotomy of the proximal phalanx, decompression osteotomy, and arthrodesis.

- Rehabilitation and return to play: conservative treatment aims at restoring the motion of the joint and strength of the intrinsic foot muscles. After cheilectomy, the player is allowed to weightbear as tolerated in a protective rigid postoperative shoe. After about 10 weeks postoperatively, running can be initiated, but caution needs to be taken that the shoes can accommodate any occurring postoperative swelling. This swelling may persist for 6–9 months after surgery.

- **Plantar Fasciitis**
  - Etiology: plantar fasciitis is the most common cause of heel pain in adult handball. It refers to a chronic inflammation at the origin of the plantar medial calcaneal tuberosity on the anteromedial portion of the heel. Analogous to the adult form, in children it's referred to as calcaneal apophysitis (Sever's disorder). In chronic cases there can occur a combined entrapment of the first branch of the lateral plantar nerve, contributing to the pain.
  - Clinical and diagnostic examination: the affected handball player usually reports pain that worsens after resting and also reports morning pain and stiffness. Typically the pain increases during rest and decreases during activity. A combined stress fracture can clinically present through swelling over the lateral side of the heel. The symptoms arise from the plantar fascia's microscopic tears and inflammation, not from the bony spurs that occur over the calcaneal edge. Frequently in plantar fasciitis with local tenderness over the heel, a tight Achilles tendon is encountered. Although malalignment is not commonly associated with plantar fasciitis, hindfoot valgus with pronation increases the peak stresses over the medial plantar fascia.
  - Treatment strategy: a nonoperative treatment protocol is commonly used for plantar fasciitis, even in a chronic setting (up to 6 months). Podiatric soft heel pads, custom orthosis (with a medial heel wedge and a first metatarsal lift to relieve the stress on the medial fascia and correct the pronation deformity) and arch taping, NSAIDS, and eccentric Achilles tendon-stretching exercises (4 min, four times a day) help in decreasing symptoms related to handball. Long-acting steroid injections (maximum 3 per year) may benefit the in-season player with plantar fasciitis but should be used judiciously since an overuse can lead to atrophy of the fat pad and make the heel pain worse [33]. Operative treatment is used for chronic cases >9 months that have failed conservative treatment with a return to sport between 3 and 4 months after a gradual increase of impact activities during rehabilitation. Due to the huge amount of different surgical techniques for chronic plantar fasciitis and due to the unsatisfactory results, the authors only recommends a surgical approach in selective plantar fasciitis cases with shared decision making. After the recovery treatment, it's advised to continue a preventative and rigorous stretching program throughout the handball player's subsequent career.

- **Sesamoid Dysfunction**
  - Etiology: handball players with cavus feet and associated plantar flexed first metatarsal head are most prone to this entity. Dorsiflexion of the first metatarsophalangeal joint causes the pain, and combined sesamoid stress fractures are usually caused by training errors itself.
  - Injury mechanism: usually repetitive microtrauma lies at the origin of sesamoid dysfunction. The cause of pain symptoms can come from a fracture, sesamoiditis (inflammation and swelling over the peritendinous structures around the sesamoids), plantar keratosis, medial digital nerve compression, osteochondritis, or bursitis [37].
  - Clinical and diagnostic examination: the player presents with localized tenderness and pain plantar to the first metatarsal head. Sometimes it's difficult to clinically differ sesamoiditis from inflammation over the adjacent flexor hallucis longus (FHL) tendon. If active plantar flexion of the interphalangeal joint against resistance exacerbates the pain, the FHL tendon is probably involved. A sesamoid view X-ray

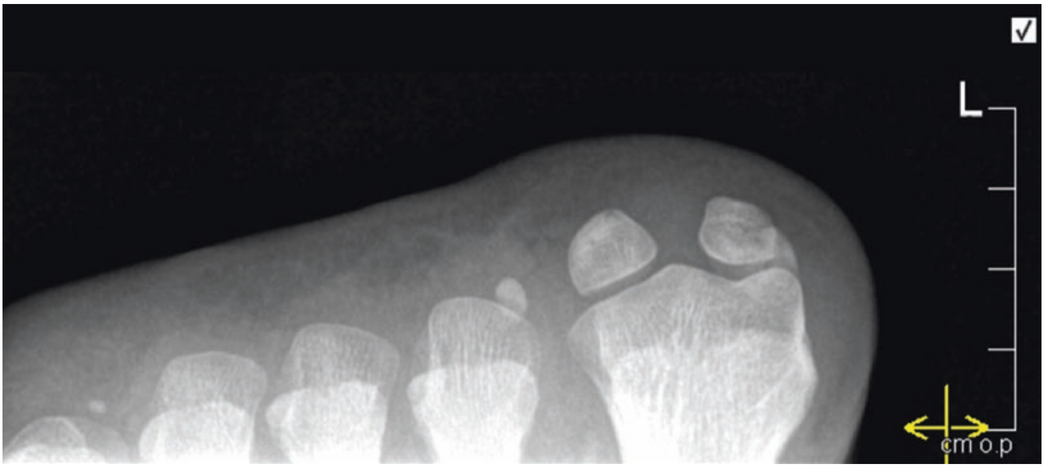

Fig. 24.13 Sesamoid view X-ray depicting a handball-induced medial sesamoid stress fracture

  and bone scan are good tools in the diagnostic setup (Fig. 24.13).

It can sometimes be challenging to differentiate a bipartite sesamoid from a fractured sesamoid on X-ray. A fracture will normally appear as a straight radiolucent line, while a congenital bipartite sesamoid will have more irregular lines.

- Treatment strategy: it will depend on the cause of the sesamoid dysfunction but is most commonly through nonoperative measures. Custom orthosis, NSAID, shoe modification, and padding are used in the treatment of sesamoiditis, especially in the case of bursitis where the main intention is to relieve the pressure under the first metatarsal head. Cortisone injections should be used judiciously in chronic cases, and only rarely an excision of a sesamoid bone in the foot of a handball player is needed. This excision can induce other problems again like progression of a pre-existing hallux valgus deformity. Total sesamoidectomy in the handball player is disadvised because of the significant biomechanical abnormalities that it can induce. Non-displaced sesamoid fractures are generally treated with a below-knee boot or cast for 4–6 weeks followed by a customized orthosis. Surgery is only indicated after failure with conservative therapy for over 6 months. Both bone grafting and sesamoid excision have yielded satisfactory surgical results in chronic nonunion cases [38].

24.8 Rehabilitation of the Injured Handballer's Foot/Ankle

After every injury (with or without temporary immobilization), the foot/ankle has to regain its flexibility toward a normal gait and its adaptations to unflat surfaces. Manual postural physio techniques aim at mobilizing again the tibiocrural joint, the subtalar joint, and the midfoot joint. Every foot/ankle injury generates a muscular atrophy and a loss of proprioception. Neuromuscular training, mobilizations, tonifications, and gait rehabilitation strategies have been shown very beneficial toward rapid recovery in foot/ankle handball problems. Troubled alignment problems will benefit from specific readaptation protocols.

If the traumatic constraints and the degenerative processes can be prevented during the treatment, a perfect recovery toward handball with normal flexibility, normal force, and adequate proprioception of the foot/ankle can be achieved. The handball player also has its responsibility in this by respecting the treatment compliance, the adaptations to the shoe (support areas), and the strict podological/pedicure protocols (Fig. 24.14).

Fig. 24.14 Image depicting the dynamics of Handball being a physical game

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25

Management of Chronic Ankle Instability in the Handball Player

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25.1 Introduction

Handball is a fast contact sport, resulting in high loading forces to both the upper and the lower limbs, leading to both acute and chronic injuries. Surveys from international and national multi-sport events have shown handball to be among those with the highest injury rate [1–3].

The rapid direction and pace changes in addition to landings from falls, collisions, and jumps present players with high injury risk during handball participation. These maneuvers, which are key elements of the sport at the top level, produce high loads to the hindfoot, frequently exceeding the mechanical resistance of the ankle joint [4, 5] (Fig. 25.1).

Epidemiologic studies have shown that the ankle, together with the knee, is the most frequently injured joint in handball practice, with reported rates ranging from 8 to 45% [6]. In terms of incidence, ankle injuries in handball have been found to occur between 0.4 and 1.6/1000 h of exposure, with ankle sprains representing the most frequent diagnosis of a time loss injury [3, 7, 8].

Injury pattern analysis over the last 10 years suggests that the incidence of ankle and thigh injuries is increasing, whereas head and knee injuries showed a decreased reported rate [9]. Improved player discipline with fewer inappropriate player contacts, and increased referee vigilance are thought to have contributed to a "relative increase" in noncontact injuries, of which ankle inversion is the most common [9].

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Fig. 25.1 Landings from a jump shot technique and quick sideways direction changes are recognized ankle injuries mechanisms in handball practice

25.2 Comprehensive Approach to Lateral Ankle Instability

Inversion ankle sprain, typically during landing on the lateral border of the foot, is the most frequent cause of acute ankle injury when playing handball [6].

This sudden increase in inversion and internal rotation, combined with either dorsi- or plantar flexion, produces loads sufficient to rupture the ankle lateral ligaments shortly after initial contact with the court [10, 11]. The anterior talofibular ligament (ATFL) is injured first, and then with increased inversion and rotation, the calcaneofibular ligament (CFL) is also torn [12].

An isolated lesion of the ATFL occurs in approximately 65% of all injuries, while combined rupture of the ATFL and CFL occurs in approximately 20%. Isolated ruptures of the CFL are rare. The posterior talofibular ligament (PTFL), also a component of the lateral ligamentous complex, is usually not injured during inversion sprain [13, 14]. In approximately 10–15% of all inversion injuries, there is a total rupture of the lateral ankle ligaments [15].

Although the natural history of ankle sprains is not fully known, the inherent stability of the ankle mortise means that complete but isolated ATFL ruptures have good prognosis. Most handball players suffering from an acute ankle injury are successfully treated with functional treatment [16]. In selected cases, especially in elite athletes, including handball, surgery can be considered as a first-line treatment to ensure an early return to sport [17, 18].

Ankle sprains, without lateral ligament rupture, can be treated with functional rehabilitation using pain as a guide to progression, leading to a relatively quick return to sports activities. Ruptured lateral ankle ligaments require 4–6 weeks of protection with bracing or taping to limit the range of motion of the ankle and allow the apposed ruptured tendon ends to heal. Overall, the use of a lace-up brace or a semirigid brace appears to be preferable to the use of taping, the latter bearing greater risk of complications, such as skin problems [17].

It is worthy to remind that standardized and reproducible criteria for a safe return to play have been poorly defined, and, at now, there are no objective guidelines to assist us in this determinant decision [19].

Despite proper nonsurgical treatment, approximately 20% of patients develop a persistent sensation of instability after an inversion ankle sprain, and are considered to suffer from functional chronic lateral ankle instability (CLAI) [17, 20, 21].

Athletes with functional CLAI complain of an inability to depend on their ankle associated to repetitive episodes of “giving way” during which the joint exhibits pathologic inversion, typically leading to associated chronic synovitis, osteochondral lesions and loose bodies.

CLAI is a consequence of both functional and mechanical factors among which the posttraumatic ligamentous insufficiency might not always be the primary causative factor [12, 22, 23]. Lower leg proprioceptive deficits, disruption of normal reflexes, and (peroneal) muscle weakness are frequently observed after an ankle ligament injury and considered major functional contributors to the persistence of the symptoms [22]. Then a comprehensive rehabilitation program that emphasizes proprioceptive, neuromuscular control, and balance training should always be considered as the first line of treatment for functional CLAI. Available data report success rates of 80–85% after functional ankle rehabilitation programs [13, 17].

Fact Box

Ankle injuries in handball have been found to occur between 0.4 and 1.6/1000 h of exposure.

Inversion ankle sprain, typically during landing on the lateral border of the foot, is the most frequent mechanism in handball.

Isolated lesions of the ATFL occur in 65% of all injuries, while combined rupture of the ATFL and CFL occurs in approximately 20%.

Despite adequate conservative treatment, approximately 20% of patients develop chronic lateral ankle instability.

25.2.1 Surgical Treatment of Lateral Ankle Instability

When nonsurgical measures fail in players with detectable posttraumatic mechanical ligamentous laxity, surgery is indicated in order to restore functional stability [16]. The surgical options to treat CLAI vary widely, from anatomical repair to nonanatomical reconstructions.

A Cochrane review by de Vries et al. showed that there is insufficient evidence to support one specific superior surgical intervention in the treatment of chronic ankle instability [19, 24].

Nevertheless, nonanatomical reconstruction tenodesis, as the Evans, Watson-Jones, or Chrisman-Snook procedures, have been showed to significantly alter the normal biomechanics of the ankle complex, particularly the subtalar joint [25, 26]. Based on these observations, as well as on data reporting sports recovery after surgical treatment of CLAI [24], anatomical procedures are currently the surgical treatment of choice in patients wishing to return to competitive handball [27–29].

The direct anatomic repair of the ATFL and CFL has been first proposed by Broström in 1966 [15] and, with the addition of the Gould modification, which includes reattachment of the lateral portion of the inferior extensor retinaculum (IER) to the distal fibula [30], has become the preferred surgical approach to lateral ankle instability. The functional outcomes have been excellent, with success rates reported as high as 87–95% [15, 30, 31].

The rehabilitation protocol after anatomic repair of the lateral ligament follows the functional treatment for acute ligament rupture, with a lower leg cast for 1 or 2 weeks, followed by 2–4 weeks in a functional brace [17]. To encourage earlier return to play, range of movement exercises and protected loading are recommended, as limited by pain. Full inversion and plantar flexion exercises should be limited during the first 4–6 weeks. Return to sport phase for handball practice usually occurs between 8 and 12 weeks; dynamic postural control tests are considered valuable functional landmarks to progress safely through the recovery process [6, 24, 32].

A major concern about the anatomic repair techniques is related to the ability of the ligamentous native tissue to achieve a strong enough repair, especially in cases of long-standing ligament insufficiency or generalized joint hypermobility. Karlsson et al. associated hyperlaxity, long-standing injuries, and previous surgical treatment as increased risk factors for inferior results following surgical repair [31].

Fig. 25.2 Anatomic reconstruction of the ATFL and CFL with free gracilis tendon graft

Objective parameters to judge the quality of the lateral ankle capsuloligamentous structures tissue are still missing, and the choice to rely on the native tissue in such critical cases remains a surgeon's decision.

In patients whose ligament remnants are judged inadequate for repair, anatomic reconstruction using a free tendon graft, usually one of the hamstring tendons, has been proposed [33, 34] (Fig. 25.2). Available clinical data indicate anatomical reconstructions as a viable option for patients with generalized ligamentous laxity or long-standing ligamentous insufficiency or as a salvage procedure in a patient with a failed Broström-Gould lateral ligament repair [33–36]; this option is possible as arthroscopic, percutaneous, or open techniques [37].

At now there is not available evidence helping the surgeon in the graft choice, which is commonly based on the surgeon's preference, case series, and the consideration of the consequences of graft harvest [2, 3].

In terms of postoperative rehabilitation, due to inherent strength of the reconstruction-type construct, athletes may perform a more aggressive rehabilitation with early weight-bearing activity compared with patients who underwent a native tissue repair. Song et al. recently showed a mid-term better ankle joint function in patients who received an ATFL reconstruction, compared with the Broström procedure [36].

Fact Box

Possible complications:

- Stiffness <5% (reduced ROM >5°)
- Re-rupture
- Neurologic problems
- Wound problems

Risk factors for worst surgical outcome:

- Hyperlaxity
- Very long-standing ligamentous insufficiency (over 10 years)
- Previous ankle joint ligament surgery
- Uncomplete treatment:
- Undepicted syndesmotic and/or medial instability
- Underestimated CFL contribution

25.2.2 Arthroscopic Options for Treatment of Ankle Instability

The current trend shows an evolution from traditional open ATFL reefing procedures to minimally invasive techniques, with an increasing number of arthroscopic stabilization techniques described and case series being published [27–29, 37–39].

Arthroscopic stabilization procedures represent an attractive option for many reasons. First and foremost, there is a potential to lower morbidity and accelerate recovery, which is characteristic for arthroscopic approaches in general [40, 41]. Moreover, given the high incidence of associated intra-articular lesions, an arthroscopic approach enables the surgeon to address both intra-articular pathology and pathological laxity simultaneously through a single approach [42, 43].

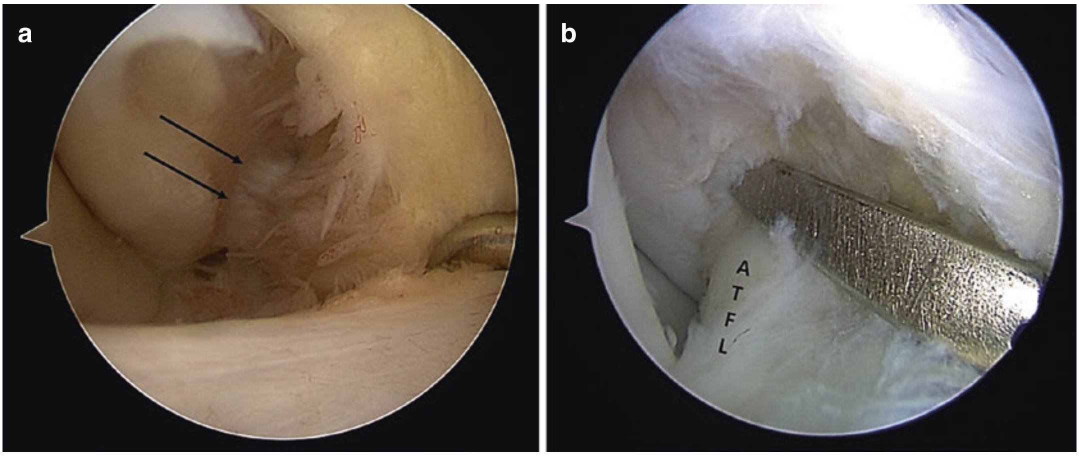

Fig. 25.3 Left ankle, arthroscope in the AM portal. (**a**) Posttraumatic ATFL fibular detachment (black arrows). (**b**) Anatomical ATFL reattachment at the fibular footprint

As for open surgery, reported arthroscopic techniques can be broadly divided in anatomic native tissue repair techniques, with or without local reinforcing using IER, often referred to as arthroscopic Broström-Gould technique (ABT) (Fig. 25.3), and anatomic ligament reconstruction with a free tendon graft [16].

Retrospective studies (mostly level IV) of arthroscopic repair techniques have shown successful postoperative outcomes with a high satisfaction rate (94.5%) and minimal complications (0.5–3%) [39, 44–46].

In addition to retrospective series, some comparative studies have been published revealing equivalent clinical and biomechanical results for open and arthroscopic anatomic lateral ligament repair [40, 41, 47].

Athletes with laxity of both the ATFL and CFL may be considered to be unsuitable for an ABT which currently only reinforces the ATFL [39].

However, the confluence of the ATFL and CFL attachments on the distal fibula indicates the potential ability of an ABT to enable a concomitant tightening of an insufficient CFL through the anatomical ATFL reattachment (Fig. 25.4) [48, 49].

Recently an arthroscopic technique of anatomical ankle lateral ligament reconstruction has been popularized, with the same indications as for open techniques, namely, long-lasting CLAI and/or failure of previous anatomical repair [37]. This technique involves complete arthroscopic reconstruction of the ankle anterolateral ligaments by means of a free tendon graft, mimicking the original course and bony attachments of the ATFL and CFL. Current available evidence is mainly limited to technical descriptions of the procedure, which has been showed to be reproducible across a wide number of surgeons experienced with arthroscopic techniques. Further research is needed to better identify the clinical value of the procedure.

Fig. 25.4 Anatomic dissection of the ankle anterolateral ligaments. The ATFL and the CFL share a common fibular insertion (*)

Fact Box

Anatomic procedures are currently the surgical treatment of choice.

Options include mainly repair of ATFL remnant or combined ATFL + CFL repair, with or without some source of augmentation (e.g., inferior extensor retinaculum).

In specific cases (e.g., poor quality of tissue remnant, revision surgeries), anatomic ligaments' reconstruction by means of grafting (either open, percutaneous, or arthroscopic) represents a valid option with growing popularity.

Arthroscopic surgical techniques for management of chronic lateral ankle instability are under development with promising results; however major evidence from comparative studies is still currently missing.

25.3 Syndesmotic Instability

The speed and the frequency of cutting actions and landing, often perturbed by contact with opponents, make handball players susceptible to ankle syndesmotic sprains.

Epidemiologic data report a syndesmotic injury to occur in 1–18% of all ankle sprains, with far higher incidences reported among the athletic population [50, 51].

Isolated syndesmotic sprains, with no concomitant fractures, also called "high ankle sprains," are the variety most frequently found in handball players.

The commonest described mechanism of injury involves an external rotation moment at the ankle with the foot positioned in dorsiflexion and pronation; syndesmotic lesions secondary to inversion trauma are less common (Fig. 25.5).

As stated by a recent ESSKA-AFAS consensus panel, the key factor during the clinical assessment of an "high ankle sprain" is the differentiation between stable and unstable syndesmotic injuries [52].

Stable syndesmotic injuries, showing no diastasis of the mortise, are adequately managed conservatively, with an overall reported rate of 86–100% good to excellent outcomes [53, 54].

Fig. 25.5 During forced external rotation with axial compression, the talus is forcibly rotated against the fibula, with rupture of the anterior inferior tibiofibular ligament (AITFL) occurring first. As external rotation continues, disruption of the IOL (interosseous ligament) follows, and finally lesion of the posterior inferior tibiofibular ligament (PITFL) occurs. The deltoid ligament is involved in the same injury mechanism

Progression to the next phase is also with the player's complaints as the guide. Full weight-bearing, as tolerated, strength training, and proprioception are emphasized, and, thereafter, sport-specific functional handball exercises can begin. The player and his entourage should be informed that the return to sport after a syndesmotic ankle sprains is highly variable, usually at 6–8 weeks postinjury and typically longer than the one following lateral ankle injuries [54, 55].

Grossly unstable syndesmotic injury, with a widened displaced tibiofibular mortise, represents a straightforward diagnosis, fortunately uncommon in handball. These lesions, usually presenting with concomitant fractures, warrant operative stabilization of the mortise, to allow appropriate healing of the ligamentous structures and a safe return to sport.

The most challenging diagnosis among acute syndesmotic injuries in the athletic population is the so-called subtle instability, which means a clinical suspicion of dynamic instability not confirmed by radiographic mortise widening.

The misdiagnosis of this clinical condition should be avoided, as it might end up with a chronic syndesmotic instability, which is a difficult condition to treat, able to affect the demanding performance of professional handball players [56].

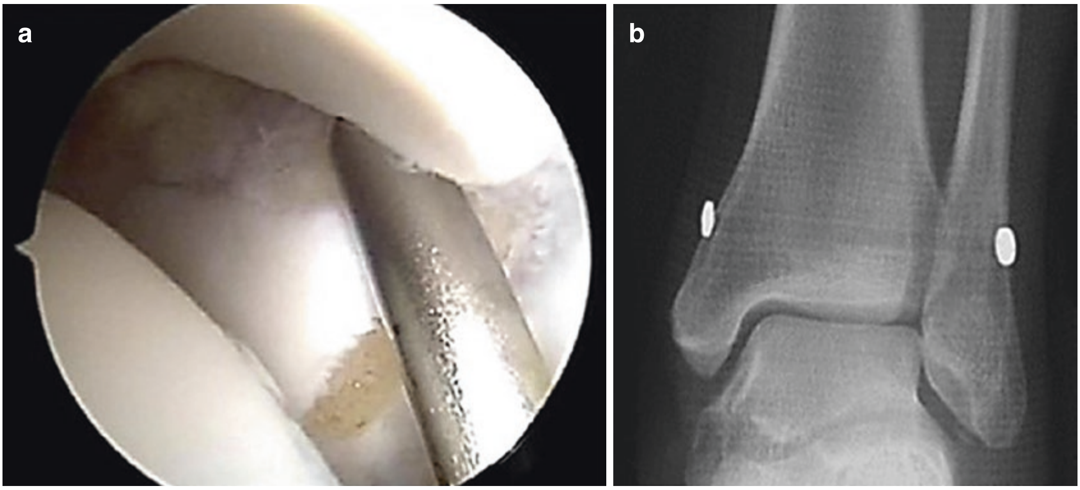

Fig. 25.6 Left ankle—arthroscope in the AM portal. (**a**) Unopposed diastasis of the mortise through a 4.0 mm shaver blade confirming syndesmotic instability. (**b**) Syndesmotic fixation with a single suture button device

The ESSKA-AFAS consensus panel has identified a series of physical and MRI signs indicating a high suspicion for dynamic latent instability. The experts agree upon the fact that such a suspicion in professional sport player is an indication for arthroscopic evaluation of the joint [52, 53, 56].

This offers the unique advantage of a dynamic evaluation of the syndesmosis under direct evaluation, with concomitant fixation, should the instability be confirmed (Fig. 25.6). The acute fixation of the syndesmosis guarantees the stability of the mortise during the ligamentous healing process, in order to minimize the risk of future chronic problems.

Calder showed 36 professional athletes undergone an arthroscopic stabilization for acute latent syndesmotic instability, all able to resume their previous sporting activities at the same competitive level [56]. Handball players are able to return to their elite competitive level after an average of 4 months following an operative stabilization of an acute syndesmotic injury [6].

By definition patients with symptomatic chronic syndesmotic injuries have usually undergone long courses of physiotherapy and exercise programs. Proposed surgical treatment methods include arthroscopic debridement, screw and suture button stabilization, anatomical reconstruction of syndesmotic ligaments, and finally arthrodesis. Available data do not support one treatment modality over another. A meta-analysis reported the pooled success rates for screw fixation, arthrodesis, and arthroscopic debridement each to be over 78%, with screw fixation being the most common treatment strategy [57].

Syndesmotic impingement pain can be alleviated by arthroscopic debridement with or without stabilization. Alternatively, a comprehensive procedure including syndesmotic stabilization should be performed, through either a ligament reconstruction technique or an arthrodesis of the distal tibiofibular joint [58, 59]. Return to preinjury sports performance level has been reported following distal tibiofibular arthrodesis [60].

Fact Box

Syndesmotic injuries occur in 1 to 18 % of all ankle sprains, with higher incidences reported among the athletic population.

Most of the syndesmotic “high ankle sprains” can be managed conservatively but often require a long time to return to play.

Latent syndesmotic instability should be recognized and treated in the acute phase in elite handball players.

25.4 Take-Home Messages

- The majority of inversion ankle sprains in handball players are adequately managed with functional treatment, even in case of ligament rupture.
- Evidence supporting the arthroscopic approach for CLAI treatment is mounting, with reported results at least equal to traditional open techniques.
- Most of the syndesmotic "high ankle sprains" can be managed nonsurgically, but a longer recovery time than inversion lateral ligament injuries has to be expected.
- Subtle syndesmotic instability should be recognized and treated in the acute phase in elite handball players, to prevent debilitating chronic syndesmotic instability.

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26

Management of Cartilage Injuries of the Foot and Ankle in Handball

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26.1 Epidemiology of Cartilage Injuries in the Foot and Ankle Injuries

In prospective season-long observation studies of handball, the lower extremity is marginally more frequently affected compared with the upper limb [1]. As with many other sports where physical contact occurs, the incidence of injury during match play of 13.5 injuries per 1000 h far exceeds training 0.8 injuries per 1000 h [2].

In common with other sports, foot and ankle injuries are among the most common in handball and comprise 20–23% of all acute injuries at elite level [3, 4] and 14–21% of injuries in international tournaments [5, 6] (Fig. 26.1) with player contact the most common aetiology (65%) and comprise up to 35% of injuries in amateur players [7]. In young handball players, foot and ankle injuries account for a similar, or even higher, proportion of injuries, ranging between 25% and 32%, again with ankle sprain being the single most common acute injury [4, 8, 9].

In terms of injury severity, it has been reported from international tournaments that 25% of foot and ankle injuries were non-time-loss injuries, while 32% of the injuries caused 1–2 days absence from training or matches, 21% up to 4 weeks absence and 7% more than 4 weeks [5]. Ankle sprains typically result in soft tissue ligamentous injuries (Fig. 26.1).

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Fig. 26.1 The use of ankle stirrups to stabilise ankles and prevent injury

The talus has fragile vascular supply being predominantly (60%) covered in articular cartilage and no attachment site of any muscle. Cartilage lesion of the foot and ankle may be pure chondral lesions or also involve the underlying bone leading to an osteochondral lesion [10]. These tend to be associated with either inversion injuries to the ankle and subtalar joint or hyperdorsiflexion injuries to the metatarso-phalangeal joint. Injuries may either occur as acute injuries or due to the development of chronic ankle instability with recurrent inversion injury leading to repetitive impact lesions.

The demographic details of those receiving arthroscopic treatment for talus lesions have been reported. Those with chondral lesions being more commonly found in older patients with a peak in the sixth decade and having had a much longer duration of symptoms. Patients with osteochondral lesions tend to peak in their 20s and have a short duration of symptoms, with males/females ratio 1.6:1. The presence of subchondral cysts (OR 3.71, 95%CI 1.61–8.55, $P = 0.001$) and soft tissue impingement (OR 1.82, 95%CI 1.1–3.03, $P = 0.021$) is more frequent in patients with chondral lesions [11].

In Orr et al.'s series of military personnel, the most common location of lesions was in the central third of the lateral talar dome, Elias' zone 6, with the majority of the lesions being type II. The second most common site was the medial talar dome, Elias zone 4, with the majority of lesions being deeper, i.e. type III [12]. Lateral lesions are probably caused by forced dorsiflexion and inversion, medial lesions by forced plantar flexion and inversion [13].

26.2 Acute Injury Management of Cartilage Injuries

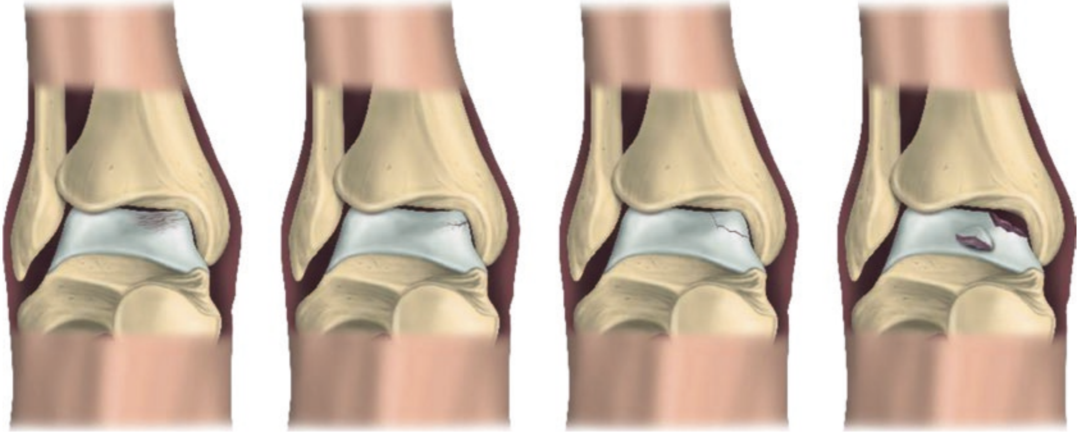
As with all acute injuries, the initial aims are to reduce further bleeding and swelling and minimise additional injury. The concept of PRICE has been superseded by POLICE, which means Protect, Optimally Load, Ice, Compression and Elevation [14].

In the acute setting, this consists of removal from play, rest preventing further injury with elevation, compression to prevent further bleeding and the application of ice to reduce soft tissue metabolism and as an analgesic. Ice application, or cryotherapy, leads to pain relief within 5–10 min, where after ice should be removed for 10 min before reapplication.

Initial firm compression using an elasticated bandage should be changed to milder compression after 20–25 min to optimise blood flow to the affected area (Fig. 26.2). The ankle should be elevated so that it is higher than the heart by 30 cm.

Protection of the injured site in the acute phase is important to avoid additional injury and further bleeding. Movements that mimic the injury mechanism should be avoided. Movement restriction can be accomplished with an elastic

Fig. 26.2 Courtside application of compressive strapping following inversion injury to minimise swelling



1. Compression
2. Partial fracture nondisplaced
3. Complete fracture nondisplaced
4. Displaced fracture

Fig. 26.3 The Berndt and Harty classification (1959) [10]

strap or ankle brace and use of crutches. Reduced load and movement restriction may be used over the initial days after injury [14] with subsequent optimal loading where partial weight-bearing and mobilisation are utilised.

Hannon et al. have reported that osteochondral lesions of the talus occur in 70% of ankle sprains and fractures [15]. Three quarters of distal fibula fractures had chondral lesions compared with 6/15 trimalleolar fractures, while only 4 in 27 bimalleolar fractures had lesions [16]. Seventy-three percent of ankle fractures are associated with chondral defects, and of patients with chronic ankle instability, 40% have been shown to have chondral lesions [13, 17].

Fractures and syndesmotic ligament injuries may be recognised by the inability to bear weight following the injury, according to the Ottawa guidelines for plain radiographs [18]. The presence of a significant rotational fracture dislocation pattern increases the likelihood of a chondral or osteochondral injury being present. There may give ongoing symptoms long after the fracture has healed.

The presence of osteochondral lesions on plain radiographs is important as early recognition may permit the planning of osteochondral fragment fixation as well as malleolar fracture fixation. Lesions may be classified based on their radiographic appearance [10] (Fig. 26.3 and Table 26.1). This has been extended to include the MRI appearance [19]. The Mintz classification has shown that MRI corresponds well with the articular surface lesion on arthroscopy [20] (Fig. 26.4 and Table 26.1).

Table 26.1 Classification of talar dome chondral lesions

	Berndt & Harty	Hepple et al.	Mintz et al.
	Plane radiographs	MRI	MRI
I	Compressed	Articular cartilage damage only	Hyperintense but morphologically intact cartilage surface
II	Chip avulsed but attached	Cartilage injury with underlying fracture ± surrounding bone oedema	Fibrillation or fissures not to bone
III	Detached chip but undisplaced	Detached but undisplaced fragment	Flap present or bone exposed
IV	Detached & displaced	Detached & displaced	Loose undisplaced fragment
V		Subchondral cyst formation	Displaced fragment

Fig. 26.4 The Mintz classification: consisting of subchondral oedema and covered bone, fibrillation and fissuring, flap present and exposed bone and finally loose undisplaced and displaced fragments

Fact Box
Chondral and osteochondral lesions of the talus should be suspected in players with persistent symptoms following ankle fractures or inversion injuries.

26.3 Natural History

The natural history of osteochondral lesions of the talus has been well described by van Dijk et al. The lesion may remain asymptomatic and heal or progress to give deep ankle pain on weight-bearing with prolonged swelling, together with the formation of subchondral bone cysts. The increased flow and pressure of the fluid into the subchondral bone may then cause osteolysis and slowly lead to the development of the cyst. The ankle pain does not originate from the aneural cartilage lesion but is likely caused by the repetitive high pressure within the cyst during loading on the sensitive highly innervated subchondral bone [21].

Klammer et al. followed asymptomatic patients with chondral lesions who received no specific treatment for 2 years. They found that 86% were pain-free at follow-up. There were no radiographic signs of osteoarthritis in 47% of patients and grades 1 and 2 OA in 27% of patients and grades 3 and 4 OA in 26% of patients [22].

Further negative long-term consequences of ankle injury include accelerated onset of ankle joint osteoarthritis, decreased quality of life and subsequently reduced levels of physical activity [23].

26.4 Nonoperative Treatment

Nonoperative treatment consists to start with of activity avoidance and protected partial weight-bearing. This is a proven management strategy for OCDs, found incidentally or asymptomatic lesions, in particular in paediatric population.

Additionally intra-articular injections may also be considered to reduce symptoms. Local anaesthetic and steroid injection may provide an analgesic effect and reduce synovial inflammation but may also impair healing. Injections of hyaluronic acid and platelet-rich plasma both have been shown to improve symptoms.

Mei-Dan et al. compared the outcomes of chondral lesions treated randomly with either hyaluronic acid or platelet-rich plasma (PRP) injections. At 28 weeks, patients had decreased pain scores and improved function. Pre-injection of the AOFAS was 68 for the PRP group and 66 for the HA group. This improved to a score of 92 and 78 at 6 months, respectively ($P = 0.05$) [24].

26.5 Operative Treatment

Operative treatments for talar dome lesions include arthroscopic procedures to remove loose bodies, debride inflamed synovium and impinging bone lesions, bone marrow stimulation techniques such as drilling and microfracture together with minimally invasive osteochondral transplantation and synthetic plug implantation. The use of autologous grafts is associated with at least 10% or higher incidence of donor site morbidity [25].

Additional procedures often include ligament stabilisation procedures such as Broström ligament reconstruction. Other techniques include allograft transplantation for large defects and autograft/allograft ligament reconstruction for persistent instability.

Recent systematic literature reviews comparing all operative techniques have not shown superior outcome for any method other than bone marrow stimulation [26, 27]. For primary treatments a systematic review of 52 studies consists of 11 prospective, including 2 RCTs, and 41 retrospective studies. A pooling method showed that marrow stimulation techniques yielded a success rate of 82% [CI 78–86%] [26].

Several studies provide specific guidance for the management of key aspects related to microfracture.

26.5.1 Lesion Size

Kok et al. in a systematic review of 198 patients followed up from 2 to 6 years showed that microfracture is a safe and effective treatment. Lesions varied in size from 0.9 to 4.5cm^2 for lesions smaller than 15 mm diameter with 81% of patients having a satisfactory result [28]. Hole geometry has been studied in a caprine model. No difference was shown between 2 mm and 4 mm deep hole groups or between the 0.45 mm and the 1.1 mm diameter holes in defect fill, osteoid and structural integrity [29]. The removal of unstable cartilage was considered important; however, the specific features of hole geometry have yet to be determined.

Choi et al. performed a retrospective comparative cohort study between subchondral drilling and microfracture, with mean follow-up of 43 months. Both treatments were effective for small- to mid-sized lesions 1.0 (0.6–1.85) cm^2 with improvements from 66.0 to 89.4 points and 66.5 to 90.1, respectively. There was no difference between the two groups [30].

A recent systematic review by Rampani et al. has shown that lesion size is a predictor of clinical outcome after bone marrow stimulation for osteochondral talus lesions. A significant correlation was found in three studies with a mean lesion area of 107.4 ± 10.4 mm^2, while none was reported in eight studies with a mean lesion area of 85.2 ± 9.2 mm^2. The lesion diameter significantly correlated with clinical outcomes in two studies (mean diameter 10.2 ± 3.2 mm), whereas none was found in two studies (mean diameter 8.8 ± 0.0 mm). The authors concluded that bone marrow stimulation was best reserved for OLT of less than 107.4mm^2 and/or 10.2 mm diameter [31].

26.5.2 Lesion Type

Both chondral and osteochondral lesions of the talus have been shown to have similarly good outcomes following microfracture with improvements in AOFAS from 64.9 to 88.8 and 68.2 to 93.5 and AAS from 2.7 to 6.4 and 2.5 to 6.6, respectively, in Park et al.'s series [32].

Choi et al. also compared the outcomes of chondral (n = 210) and osteochondral (n = 88) lesions and showed no clinical difference in outcome. Chondral lesions improving from 61.2 to 85.1 points and osteochondral from 62.1 to 85.2 points at 49.8 months and 56.5 months, respectively [11].

Clanton et al. have reported on the outcomes following microfracture of grade III and IV lesions of the articular cartilage of the ankle in 40 patients. The mean talar defect size was 70 mm^2 and the tibial defect size smaller at 31 mm^2. Patients, who previously had undergone ankle surgery, had a lower level of function than those that had not [33].

26.5.3 Drilling and Microfracture

Takao et al. performed arthroscopic debridement and drilling to chondral (n = 13), subchondral (n = 10) and chondral-subchondral lesions (n = 49). Patients reported AOFAS outcomes of 91, 93 and 99 points, respectively, at 39 months follow-up. Drilling did not improve the MRI and arthroscopic appearance of the three respective lesions [17].

Antegrade transmalleolar drilling has been considered as a method of gaining access to posterior third lesions in the talar dome; however, this technique has a risk of iatrogenic cyst formation within the tibia [34], with the tibial drill holes forming a tract for passage of joint fluid.

The technique of microfracture is similar to that performed in the knee [35] (Fig. 26.5). Access to central talus lesions is performed by plantar flexing the ankle so that access to the lesion is achieved without passing instruments between the chondral surfaces. For posterior third talar lesions, posterior ankle arthroscopy can be performed by dorsiflexing the ankle [36].

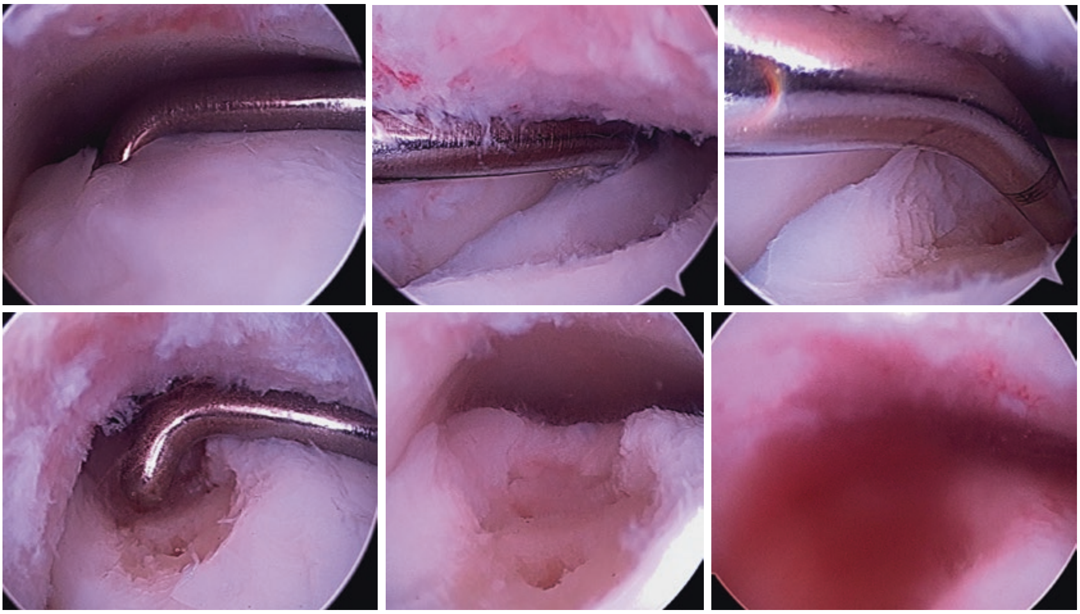


Fig. 26.5 Microfracture

Fact Box
The primary recommended operative treatment is microfracture, which will lead to good clinical outcome in the majority of cases.

26.5.4 Presence of Cysts

Lee et al. compared the outcome of chondral lesions with and without the cyst being treated with microfracture and showed a similar outcome at 48 months follow-up with AOFAS scores improving from 64.8 to 91.8 for those with a cyst and from 66.2 to 91.3 for those without a cyst. The authors recommended that in the presence of a subchondral cyst, the primary treatment should be microfracture rather than osteochondral transplantation [37].

26.5.5 Outcome Long-Term Scores, CT, MRI and Arthroscopy Findings

Polat et al. have reported on the long-term results of microfracture of the talus and arthroscopic debridement. The mean defect size was 1.7 ± 0.2 cm^2. Patients were followed up at 10 years, and AOFAS scores were found to be 85.5, compared with a pre-op score of 58.7. Comparable to other studies, 42.6% of the patients reported no symptoms, 23.1% reported pain after walking for 2 h and after competitive sports, and 32.9% had a one-stage increase in arthrosis level according to the Takakura Radiologic Arthrosis Classification System [38].

Becher and Therman reported prospective scores following arthroscopy and microfracture at 24 months. Eighty-three percent reported excellent or good scores using the Hannover scoring system, while all had fissuring and fibrillation on MRI at follow-up [39].

Lee et al. performed a second-look arthroscopy on 21 talus lesions treated with microfracture at 1 year. Although excellent/good AOFAS scores were reported in 90% of the patients, 40% had abnormal findings at arthroscopy [37].

Relingh et al. have recently performed a prospective comparative study of patients with chondral lesions and cysts who underwent either microfracture or a lift, drill, fill and fix (LDFF) procedure. At 1 year following the procedure, there was no difference in terms of AOFAS or numeric rating scales during rest and running. There was, however, a difference in the subchondral bone plate in patients treated with the LDFF procedure compared with microfracture ($P = 0.02$). This may result in less future osteoarthritis with improved long-term outcome [40].

26.5.6 Biological Augmentation

Doral et al. have performed a RCT of patients following microfracture of a talar dome lesion, showing that those that received intra-articular injections of hyaluronic acid demonstrated improved outcome compared with controls [41] although this has been considered to be insufficient evidence for firm recommendations [42].

26.5.7 Role of Secondary Procedures

In terms of ongoing symptoms following primary treatment, multiple different treatment options have been considered. A recent systematic review has identified 21 studies with 299 patients with 301 OCDs that failed primary surgery. A simplified pooling method calculated a mean success rate of 90% [CI 82–95%] for osteochondral transfer procedures, 65% [CI 46–81%] for mosaicplasty and 55% for osteochondral allograft transfer procedure. Given the methodological concerns, it was considered to be inappropriate to draw conclusions from these results [27].

26.5.8 Safe for Athletes

Vannini et al. reported the findings of a systematic review of the treatment of osteochondral lesions of the talus in athletes. They reviewed 16 studies including 642 patients with lesions. The authors commented that there was a significant use of microfracture due to relatively earlier return to weight-bearing and return to sports activity. None of the other reported strategies result in superior outcome compared to microfracture [43].

26.6 Rehabilitation

Following marrow stimulation for talus lesions, early weight-bearing at 2 weeks was found to give similar results compared with delayed weight-bearing until the 6 week time point, with AOFAS scores increasing from approximately 64–89 points following surgery in both groups [37].

Lundeen has reported a small series ($n = 11$) of lesions of large lesions >150 mm^2 after bone marrow simulation. Patients were permitted immediate unrestricted post-operative weight-bearing and mobilisation, and at follow-up of 33 months, an AOFAS of 82 points was reported [44].

Fact Box
Players can be partial weight-bearing at the 2-week time point following surgery.

26.7 Return to Play

Following the initial period of recovery postsurgery allowing swelling to reduce and range of motion to improve, gradual rehabilitation through a criterion-based programme is recommended. Return to play following ankle surgery has been divided into four phases consisting of the resumption of walking and jogging, followed by return to non-contact activity with careful avoidance of sudden direction changes and finally the return to contact activity with sudden direction changes [45].

Return to play and activity is important in the competitive recreational, elite and professional athlete. Sullivan has reported a case of a professional rugby league player who had single stage autologous chondrocytes surgery. Cartilage and bone chips were placed into a porous collagen scaffold, which was implanted in a 15 mm defect for which bone marrow stimulation had failed. From 2 weeks the player had a full range of ankle movement and was weight-bearing from the 6 weeks point following surgery. He returned to play at 23 weeks, and when reviewed at 24 months, he reported no pain and no restriction in activity; however, there was mild limitation of ankle dorsiflexion from 20° to 12°.

Return to play was studied by Savva et al. who noted that not only does repeated arthroscopic debridement yield results with an AOFAS of 80.5 points at 5.9 years compared with presurgery scores of 34.8 [46]. Out of 12 athletes, 2 returned to professional sports, 6 returned to the preinjury level and 3 to the same sports but at a lower level of play. In Vannini's review patients returned to activity over a wide range of time between 16 weeks and 1 year [43].

26.8 Other Lesions in Foot and Ankle

First Metatarso-phalangeal Joint. Frey and van Dijk have described arthroscopy of the first metatarso-phalangeal joint; however, it is a technically advanced procedure [47], and only a few case series are reported in the literature [48]. Kuyucu reported on 14 patients with hallux rigidus treated with arthroscopic micro-drill holes. AOFAS scores improved from 48.6 to 87 at 16 months follow-up [49].

26.9 Take-Home Messages

Secondary procedures are indicated if primary microfracture does not lead to symptom alleviation.

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27

Back Injuries and Management of Low Back Pain in Handball

Rui Rocha

27.1 Introduction

Low back pain (LBP) is a common entity in the general population, there is a lifetime incidence of 60–90% of LBP, but only 4% of these patients will need surgical intervention [1–4]. LBP is a symptom with multiple diagnostic possibilities. More often there is no correlation between the pain and an anatomical abnormality, and this could be a challenge to the attending physician. History of past events of LBP reflects a risk factor for recurrence of the condition [5–7].

Competitive sports require repetitive demanding physical exercises with high loads on the spine. Elite handball players are exposed to such loads from an early age [8]. The estimated prevalence of LBP related to sport ranges between 1 and 30% [9, 10]. LBP is the most common cause of lost playing and training time in professional players [9, 11]. Most episodes of LBP are of low intensity, and the professional athlete will continue to compete despite the discomfort [12]. Players rarely report the condition, so the prevalence may be higher, and most of the times, the adequate treatment and rehabilitation will not be completed.

Handball is played by about 20 million players around the world [13] and is a high-intensity sport with high physical contacts between players, multiple-direction sprints, jumps, landings, sudden changes in direction and repeated acceleration and deceleration movements. In spite of that, handball players are prone to the same prevalence of LBP as other sports. There are no exhaustive and prospective randomized studies in the literature specifically for handball players. Moller et al. followed 517 elite players in 3 age groups, senior, U-18 and U-16, recording a prevalence of 7, 5.3 and 4.9%, respectively, for traumatic injuries and 3.5, 11.9 and 5.9%, respectively, for overuse injuries. Giroto [13] reveals that the incidence rate of injuries during training is 3.7/1000, and during matches is 20.3/1000, and that lumbar spine injuries are traumatic in 8% of the cases and overuse in 4% of them. It is known that the duration of training, its intensity, variety and the lack of rest are factors that are related to LBP in every sport. Furthermore, the prevalence of LBP suffers variations with playing positions [14].

The most common forms of back pain affecting athletes can be prevented by recognizing epidemiologic patterns and implementing treatment plans accordingly. Increased knowledge on the prevalence of LBP will be helpful for determining strategies of prevention training and practice [14]. The majority of the cases are self-limiting and respond well to conservative treatment. But there are a number of disorders that will need a more exhaustive evaluation and management.

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Prevention of injuries is the key word to reduce the prevalence of LBP between handball players.

27.1.1 LBP: General Approach

LBP is a symptom, not a diagnosis, and is considered to be acute or chronic in nature. However it is important to note that LBP is a dynamic entity and may oscillate over time, with asymptomatic periods between recurrences.

The natural history of LBP in handball athletes is no different from the general population. Sport participation contributes to less frequent episodes of LBP. But this is true only until the first time appearance of LBP. From that moment on, sport activities might increase the severity of pain and its recurrence [15].

It is difficult to reach a consensus as to the exact prevalence of LBP in athletes, as they are resilient and always want to play and train so that they do not lose their place in the team. In handball, as in all sports this is what happens on a daily basis, not favouring the collection of statistical data and challenging the field doctor.

27.1.1.1 History and Physical Examination

It is important that the physician is familiar with the sport of handball and the various possible injuries, injury mechanisms, as well as the most frequent overuse injuries. The approach to a diagnosis must be comprehensive with focus on the player's age, the presence of "red flags" and the possibility of facing a serious injury.

When obtaining clinical history, it is important to characterize the mechanism of injury where appropriate, to determine the characteristics of the pain, as well as possible pain radiation and factors which may worsen or relieve it. It is also important to know the past clinical history of the athlete to determine if we are dealing with a new episode or a worsening of a chronic situation.

History taking identifies potential "red flags". These are symptoms or conditions that may be present and indicate a more serious pathology. The presence of "red flags" recommends the need for further investigation and specialist referral. The absence of "red flags" facilitates a safer progression with the diagnostic possibilities. Potential "red flags" in history or physical findings are major trauma with possible fracture, fever or chills, recent bacterial infection or immunosuppression with possible infection, history of cancer, weight loss, pain at multiple sites, pain that worsens at rest or at night, failure to improve with treatment, pain that persists 4–6 weeks, severe or progressive sensory alteration or weakness, bladder or bowel dysfunction and evidence of neurological deficit in legs or perineum. It is important to exclude fractures, rheumatological or inflammatory diseases, infections and tumours.

The most common sports-related back injuries, especially in young handball players, are sprains and strains, disc-related back pain, spondylolysis, spondylolisthesis, stress fractures and atypical Scheuermann kyphosis. Adult athletes with LBP have greater risk of disc-related back pain than nonspecific mechanical back pain.

Another type of flags, the "yellow flags", may require the need to address psychosocial factors. These are psychosocial indicators suggesting increased risk of progression to long-term distress, disability and pain. They can relate to the patient's beliefs, emotions, behaviours, family and workplace. Future research is mandatory to investigate the relevance of these issues in athletic population.

Physical examination should be equally exhaustive and incorporate a range of motion assessment, palpation and traditional orthopaedic and neurological testing procedures to inform if further investigation is required. Lumbar flexion stresses the anterior spine with multiple possible pathologies: disc pathology, epiphyseal injury and Scheuermann disease. Lumbar extension exercises hurt the posterior spine with possible spondylolysis/spondylolisthesis, facet pathology, hyperlordosis syndrome or lumbar muscle strain.

27.1.1.2 Investigation

It is not necessary to thoroughly investigate every LBP. In most cases even a plain radiograph is not necessary if there are no alarm elements in the clinical history and physical examination.

When the presence of active disease is suspected, it is possible to choose several auxiliary diagnostic tests according to the situation, symptoms and existing findings: radiographs demonstrate spinal deformities, instabilities and spondylolisthesis. Magnetic resonance imaging (MRI) scans show vertebral discs, infections, tumours and the spinal cord. Computed tomography (CT) scans illustrate fractures and bone abnormalities. Bone scans can demonstrate suspected infection, inflammatory disease, tumours or stress and lytic pathologies. Laboratory tests may be helpful with certain diagnoses such as infection, inflammatory conditions and malignancy.

The physician must be conscious of specific signs that warrant further investigation. Diagnostic imaging should be used in an evidence-based and targeted fashion. When red flags are present, imaging studies are mandatory and are tailored to the situation, the history and the physical examination.

27.1.1.3 Management

It is essential to establish a diagnosis not to make gross mistakes in the rehabilitation of an athlete.

In order to establish an appropriate recovery strategy, a multidisciplinary approach with the contribution of all the agents involved in the recovery of the athlete, starting with the coach, physiotherapist, managers, teammates and physician, is essential. Many athletes need to change training plans, sometimes even the technique of playing the sport.

The McGill [16] recommendations on how to reduce the risk of low back injuries in athletes are very useful in daily practice. Evidence supports the principles to modify activity, remain active and replace aggravating activities for non-aggravating actions—relative rest [17, 18]. The recommendations include avoid end range of spine mobility in the first training days and spare the spine from full lateral bend, full flexion or extension and full rotation. Warm up is essential; the reduction of reaction moments and full contact is advisable. Management also includes modifications in training [19], discussions should be made with coaching staff to develop a period of relative rest and activity modification, and, if relevant, technique adjustment is made to prevent the cycle of recurrent exacerbation and chronic pain.

Management of the other specific pathologies is discussed ahead.

27.1.2 Nonspecific Injuries

27.1.2.1 Soft Tissue Injuries

Soft tissue injuries are the most commonly prevalent in athletes with low back pain. The intensity of training, the repetitive movements, the progressive loads and the sudden changes of speed are factors that contribute to the appearance of this type of lesions. However, there are other causes for the appearance of LBP: the poorly prepared athlete, lack of exercise on safety precautions, changes in the physical environment of the training or the restart of activity after a period of rest, such as in the beginning of the season.

The anatomy of the athlete’s spine is no different from that of the nonathlete. When the back is submitted to stress forces, the physiology and biomechanical principles that rule general population are the same for handball players.

Sprain is a ligamentous injury, while a strain affects a muscle, tendon or musculotendinous junction. In sprains, some fibres of the spinal ligaments may be hurt, but the continuity of the ligament is maintained. The most commonly affected ligament in lumbar spine is the intraspinous [20].

Strains occur by interruption of muscle fibres within the muscle belly or in the musculotendinous junction. Pain is more severe 24–48 h after injury and is associated with muscle spasm that may be localized latter to a trigger point [20]. Repeated muscle strains have asymptomatic periods between crises. Chronic strains are characterized by continued pain attributable to muscle injury. Athletes with lower extremity acquired ligamentous laxity or overuse may be at risk for the development of noncontact LBP during athletic competition [12].

Adolescent players cannot and should not be regarded as adult athletes. The anatomy of young people is different and is constantly changing. Incidentally, this is one of the possible causes of LBP.

In the growing period, there are anatomic and physiologic changes in the spine that represent different patterns of LBP. Hyperlordotic LBP is the second most common cause of back pain in the adolescents [21, 22]. Another juvenile characteristic is that, during growth, axial skeleton tends to develop more quickly than the surrounding fascia and muscles. This will cause pathologic stiffness and rigidity resulting in LBP.

The intrinsic characteristics of an athlete are also important factors to consider in approach to LBP. These include abdominal weakness, thoracolumbar fascia tightness, iliopsoas inflexibility, femoral anteversion, genu recurvatum and hyperelasticity. Iliopsoas inflexibility increases lumbar lordosis and shear forces to the intervertebral disc. Understanding intrinsic defects and considerate their interaction with sport-specific forces can help to anticipate possible injuries and predict rehabilitation.

Clinical history and physical examination are important in the evaluation of these lesions. In most cases, there is no associated trauma, or the athlete can’t point to a specific initial event. The most common symptoms are lumbar muscle spasm and local tenderness provoked by bending, twisting and weight bearing, without radiculopathy. In a spasm of the lumbosacral fascia extending to the tensor fascia lata, the pain can often radiate to the hips.

Physical signs may include local bruising and swelling or a spasmodic scoliosis. When the traumatic event is violent, the physician should consider underlying fractures or internal organ damage.

In patients with no “red flags”, no specific imaging is necessary. Conservative treatment with rehabilitation addressed to specific problems, symptomatic treatment with ice or heat, depending on the timing of the injury and occasionally deep tissue massage. It is important to improve core strength and control, flexibility and overall range of motion (ROM). Ninety percent of back pain resolves within 10 weeks of initial symptoms. The player who suffered low back pain or strain can return to sport when symptoms free and full ROM is obtained. A wider investigation is needed if the symptoms persist with adequate treatment for more than 2 weeks.

27.1.3 Lumbar Disc Disease and Lumbar Disc Herniation

There is no consensus for the aetiology of vertebral disc disease. It is thought that this is a multifactorial condition in which hereditary, physical, hormonal, physiological, occupational and health characteristics contribute to the installation of the pathological entity.

Intervertebral discs have an important biomechanical role within the spine, as they permit motion between the spinal segments while diffusing compressive, sliding and torsional forces [23]. Deterioration of the disc decreases its ability to resist to extrinsic forces, as they are no longer transmitted proportionally and are strongly associated with LBP. Disc degeneration involves structural disruption as well as cell-mediated changes in composition.

Discs have a tendency for degeneration earlier than other musculoskeletal structures, with adolescents presenting signs between the ages of 11 and 16 years [24]. It is particularly susceptible in exercises with repetitive flexion, or hyperflexion, combined with lateral bending or rotation [25]. When these movements are combined with axial compression, there is a distress of the internal structure of the disc.

The annulus fibrosus is the weakest area of the intervertebral disc and is the most susceptible area to herniation of the nucleus pulposus (HNP). HNP results from repetitive torsional forces with lumbar flexion. Acute HNP accounts for approximately 10% of back pain in adolescent athletes.

Participation in sports appears to be a risk factor for the development of disc degeneration. Disc degeneration seems to be influenced by the type and intensity of the sport. Like most of the people, handball players show disc degeneration almost exclusively at the L3 to S1 levels.

27.1.3.1 Clinical Presentation

It is very difficult to correlate lumbar pain with the intervertebral disc. In addition, as verified in the general population, complementary diagnostic imaging does not always aid much since many in general population show disc changes on plain radiographs, CT scan or MRI with no lumbar pain.

The pathogenesis of disc pain is explained only partially by the mechanical pressure of the disc protrusion. Symptoms of acute disc herniation may occur with minimal disc changes visualized by MRI. Secreted cytokines, such as phospholipase A2 and nitric oxide that stimulate inflammation at the dorsal root ganglion, have been identified. The nucleus pulposus itself may be a direct neurotoxin to the dorsal root ganglion.

In adolescents, herniated discs tend to be more central than in adults. The symptoms are necessarily very variable, often presenting with tension signs of sciatica; however, many athlete will present with nonspecific buttock, low back or posterior thigh pain, neurogenic scoliosis and hamstring tightness. Examination usually reveals decreased lumbar motion, a positive straight leg raise test and possibly a decrease in reflexes or strength.

Cauda equina syndrome is an infrequent but significant clinical entity in patients with back pain. It typically presents in more acute fashion with the characteristic findings of saddle paraesthesia, bowel or bladder incontinence or retention and occasional radiculopathy at the lower lumbar levels; back pain also can be one of the findings. Cauda equina syndrome is a surgical emergency.

Disc herniation is managed successfully with a multidisciplinary approach. Physical therapy is initiated with an extension-based stabilization programme when the patient is able to support it. Therapy includes a trunk and pelvic flexibility and isometric strengthening programme. The pain management service assists with medication, such as the tricyclic antidepressants, neuroleptic agents and epidural corticosteroids injected under imaging guidance. Surgical management is necessary only for cauda equina syndromes, a progressive neurologic deficit, and refractory pain not responsive to conservative measures.

Handball players with disc herniation may return to competition when they are pain-free and have attained a full range of motion, strength as well as sport-specific attention to technique.

27.1.3.2 Diagnostic Imaging

Initial assessment of discogenic pain requires anteroposterior and lateral radiographs. Flexion and extension lateral radiographs can be used to show mobility across the lumbar segment or instability.

Lundin proposed that the radiographic finding that most strongly correlated with LBP was decreased disc space height [26]. It is more likely to have LBP when more levels are involved. Plain radiographs may be normal in cases of lumbar disc herniation.

MRI is the method of choice to study the disc and is highly sensitive to degenerative changes such as loss of signal intensity on T2-weighted images (Fig. 27.1), annular tears and associated bone marrow vertebral endplate changes defined as Modic [27]. The clinical significance of Modic changes is controversial. Decreased signal intensity within the disc correlates with LBP in athletes and in nonathletes [28]. MRI is also the

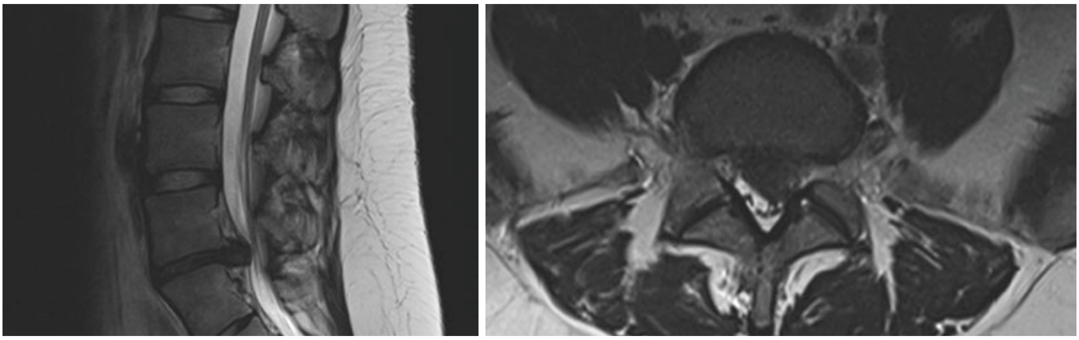

Fig. 27.1 L5-S1 left lumbar disc herniation MRI

most sensitive test for detecting herniation and nerve root compression [29].

Discography, although less used nowadays, is another possible method to identify LBP of discogenic origin. Reproduction of a patient's typical LBP with discography suggests that leakage of interdiscal fluid or annular distension is involved in the production of back pain.

27.1.3.3 Nonoperative Treatment

Nonoperative treatment is the gold standard for the approach to discogenic LBP in the athlete. Several rehabilitation protocols have been suggested specifically for this condition. Cooke's five-stage protocol [30] is one good example of physical therapy and is composed by the five stages: early protected mobilization, dynamic spinal mobilization, spine safe strengthening and conditioning training, return to sports and maintenance programme.

Each athlete at each position has a unique clinical picture, and the recovery pattern will depend on the personalized rehabilitation programme. The wing will have different physical demands compared with the goalkeeper or the pivot.

Lumbar disc herniation rehabilitation protocol is similar to that of discogenic back pain, and the return to sports activity happens when the athlete is free of symptoms. Ninety percent of the athletes with disc herniation improve with nonoperative treatment. Therapy goals are always pain reduction and decreasing the length of symptomatic episodes.

27.1.3.4 Operative Treatment

The traditional operative indications for discogenic pain are mechanical LBP correlated with positive findings on imaging, continuous symptoms for at least 6 months despite active nonoperative treatment and localized midline spinal tenderness that corresponds to the radiographic level of the disease [9]. Surgical treatment is either total disc replacement or lumbar fusion. The authors don't recommend surgical treatment for disc disease without herniation because it has unpredictable clinical outcomes even for the general population. In high-level athletes, there are few reports concerning operative treatment for discopathy. The authors don't support surgical treatment in pure discogenic back pain.

Disc herniation indications for surgery are more consensual: progressive neurological deficit and radicular pain that does not respond to conservative treatment are the two main indications, and the results in athletes are excellent in terms of return to play and elimination of radiculopathy.

27.1.4 Spondylolysis and Spondylolisthesis

Spondylolysis is a defect of the posterior part of the osseous vertebral neural arch. The most common region affected is the isthmus of bone between the cephalad and caudal articular processes—pars interarticularis. It is most frequently affected at L5 (85–95% of cases) and L4 (5–15%).

Athletes with back pain lasting for more than 3 months are 40% likely to have spondylolysis. Predisposing factors are hyperlordosis, pre-existing dysplasia, iliopsoas inflexibility, thoracolumbar fascial tightness and abdominal weakness. The aetiology of isthmic spondylolysis is not well known. It is thought to be a stress fracture caused by repetitive loading or bony impingement of the pars of L5 sheared by inferior articular process of L4 and superior articular process of S1. Sometimes it occurs in patients with congenital pars defects. The lesion can lead to the development of an anterior listhesis, which is the slippage of a vertebral body over the one below.

Most can remain asymptomatic and may not be diagnosed until adulthood. Twenty-five percent of the symptomatic cases are linked to any type of listhesis. The prevalence of spondylolysis in the adolescent athletes is estimated to be near 25%. Sports requiring hyperextension movements of low back have proven to be a risk factor for the development of spondylolysis [31, 32].

Bilateral pars defect will develop symptomatic progression only in a few cases. Unilateral pars defects are not connected with spondylolisthesis or incapacity [33].

27.1.4.1 Clinical Presentation

Most cases are asymptomatic. About one quarter of symptomatic cases are associated with spondylolisthesis. There are three classic patients at presentation: female, hyperlordotic and hypermobile; male, hypomobile/inflexible with tight paraspinal musculature; or someone new to a sport, deconditioned with poor core [33–35].

The main symptom is low back pain aggravated by extension. If the pain radiates, it does so to the buttocks or the back of the thigh and is more commonly from hamstring tightness than from radiculopathy.

Inspection can demonstrate exaggerated lumbar lordosis from increased sacral inclination without a slip or from a spondylolisthetic deformity. With higher-grade spondylolisthesis, the buttocks can appear heart-shaped, and a midline step-off between the spinous processes can be palpated. Point tenderness on palpation of the affected spinous process can be present in cases of spondylolysis alone. Straight leg raising can demonstrate hamstring tightness; however, generally it does not reproduce radicular pain. Neurologic examination is usually normal. Pain can be aggravated by extension of the lumbar spine, which is often triggered during examination (adding side bending towards the affected side—Kemp test). The Stork test has low specificity and low sensitivity [36, 37].

27.1.4.2 Imaging

Anteroposterior, lateral and both right and left oblique views must be obtained. Twenty percent of the defects are unilateral and will be missed without both oblique radiographs. Eighty-five percent of the defects are appreciable on the oblique view. Early stress lesions can be missed on radiographs [38].

When plain radiographs of a patient with persistent symptoms reveal negative findings, a bone scan, computerized tomography scan or a magnetic resonance imaging scan should be used. There isn't a consensus on imaging, radiation exposure in the adolescent and growing technology helping magnetic resonance imaging to potentially become a more sensitive option.

Single-photon emission computed tomography (SPECT) has high sensitivity and can localize the lesion, provide early diagnosis of active lesions, differentiate between acute and chronic non-union and stablish correlation between pain and aetiology. Yet, it has poor specificity, radiation exposure (less than the computed tomography scan) and intravenous injection and can't detect alone a chronic non-union.

Computed tomography scan is the most sensitive and specific independent imaging modality to determine a complete or incomplete pars fracture (Fig. 27.2). It can help stage the chronicity of

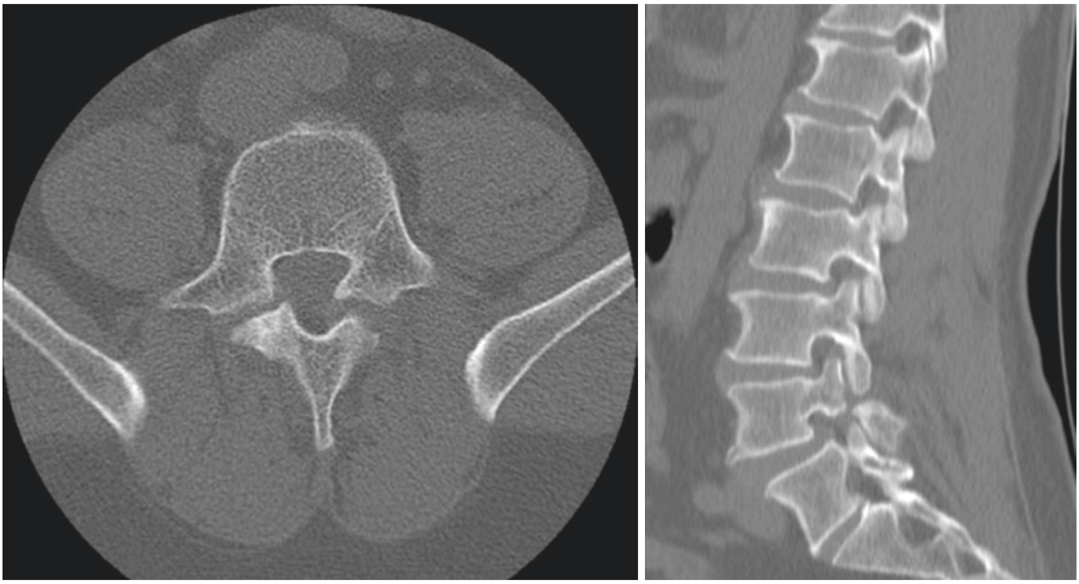

Fig. 27.2 L5 spondylolysis CT scan

the lesion (wide/sclerotic, chronic; narrow/non-corticated margins, acute). It can evaluate bone healing and aid in surgical planning. Its radiation exposure is a downside.

Magnetic resonance imaging scan is reliable for early/stress lesions, for acute and complete lesions and for chronic ones. Its benefits are the absence of radiation and the visualization of other possible causes of low back pain. It has lower sensitivity for incomplete fractures. The existence of a high signal change in the adjacent pedicle, on a T2-weighted MRI scan, is found to be a good predictor of bony union [39].

Negative CT scan and positive SPECT show a stress response pre-lysis with good prognosis for healing and bone union. A positive CT scan and a negative SPECT show a non-union of a chronic lesion [39].

27.1.4.3 Proposed Imaging Protocol

Lumbar radiographs (anteroposterior, lateral and both oblique views).

If negative: MRI for initial screen.

Localized CT scan for positive spondylolysis on MRI (staging the lesion) or for symptoms prevailing with normal MRI.

If all negative: SPECT.

27.1.4.4 Conservative Management

Most players will respond well to nonoperative treatment with analgesics, AINEs and physical therapy with core strengthening. Persisting pain may be an indication for surgery. Decision-making is often difficult as professional handball players are concerned about their future performance and the possibility of future relapses of lumbar pain.

Initial management is activity restriction, immobilization and pain treatment. The use of a brace is controversial as well as the type of brace. When choosing a brace, we must opt for the solution that combines comfort and sufficient limitation of extension. There are many types of braces: lumbar-sacral orthosis (LSO), antilordotic thoraco-lumbar-sacral orthosis (TLSO) or Boston brace antilordotic and corset/soft brace. The duration of immobilization is another controversial subject. We recommend the use of a brace 2–6 months for 23 h a day. However the majority of authors have agreed that athletes can return to play when they are pain-free, regardless the time that has passed since the beginning of the symptoms or whether there is radiographic evidence of pars healing [40]. A physical structures rehabilitation programme is recommended before return to play, even in pain-free athletes. Initial activities must be focused on core muscle strengthening and lower limb flexibility.

Bony stimulation is another option considered if the athlete has pain and no healing at 4 months of treatment. The reports are contradictory as to their effectiveness.

If pain persists after 1 month, surgical treatment is an option [40].

27.1.4.5 Surgical Treatment

The surgical technique depends on the clinical and physical evolution of the pathology. The techniques can be separated in three categories: direct repair of spondylolysis when there is no slippage or a grade 1 slippage without disc pathology, decompression alone when radiculopathy is the only presentation in an older patient and decompression and in situ fusion or reduction and fusion.

When there is a pars defect without spondylolisthesis or a pars defect with grade 1 spondylolisthesis with no disc disease, iliac autograft and temporary fixation with transpedicular screws are a good solution. When the disc is affected with spondylolysis or grade 1 spondylolisthesis, we recommend minimally invasive transforaminal lumbar interbody fusion (MI-TLIF) (Fig. 27.3)

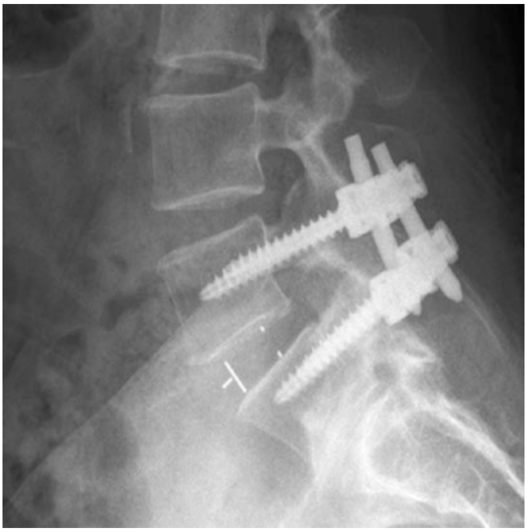

Fig. 27.3 MI-TLIF

or open TLIF. For grade 2 spondylolisthesis and above, we recommend reduction and 360° fusion or in situ fusion without reduction [40].

Following surgical treatment, the role of physical therapy is determinant in the recovery and return to competition.

27.1.5 Other Causes for Vertebral Originated Pain

27.1.5.1 Scheuermann Disease

Scheuermann disease (SD) is considered to be a form of osteochondrosis of the spine and is defined by increased kyphosis of the thoracic spine with structural deformity of the vertebral elements. It can be painful in the acute phase and may cause significant truncal deformity that may be progressive.

Type II SD or lumbar form of the disease constitutes one of the causes of LBP in athletes. This condition presents with localized back pain and radiographic vertebral changes at the thoracolumbar junction and is not typically associated with significant clinical kyphosis. Schmorl's nodes (Fig. 27.4) and endplate irregularity may be so severe that SD could be confused with infection, tumour or other conditions.

Unlike classic thoracic Scheuermann kyphosis, its course is nonprogressive, and its symptoms resolve with rest, activity modification, physical therapy and time.

27.1.5.2 Vertebral Stress Fractures

There are many types of stress fractures; most of them occur in poor-conditioned athletes or in those submitted to heavy loads. The majority of stress fractures occur in the lower extremities, but they can occur in vertebral bodies. Spondylolysis can be considered as part of the stress fracture spectrum, but other types include vertebral endplate fractures in the adolescent due to growth cartilage and undeveloped ossification centres and vertebral body stress fractures.

Stress fractures result from repeated submaximal loads causing fatigue of the bone structures. These fractures occur when the stress implicated in the bone is greater than the capacity of the bone to heal. Bone turnover depends on genetic, hormonal, mechanical and nutritional factors. The repetitive microdamage and the incapacity to keep appropriate skeletal repair (fatigue reaction or fracture) are characteristics of stress fractures in the athlete [40].

The prevalence of stress fractures is unknown since the majority of them are not diagnosed.

Plain radiographs are usually normal, and the most common method for diagnosis is a bone scan, which can detect the fracture as early as few days after it occurs. MRI is not as sensitive

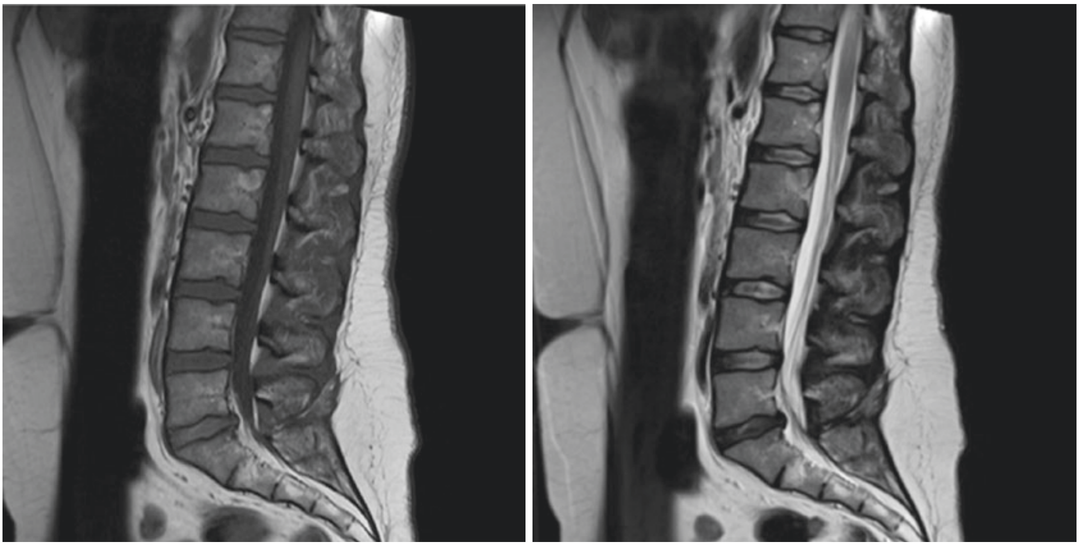

Fig. 27.4 Schmorl's nodes

as bone scan; however, it does enable to exclude other possible causes of pain. CT scan is another modality with good accuracy in the literature for detecting stress fractures [40].

Treatment should consist of a period of rest and physical rehabilitation; in some cases surgical treatment is required fixing the fracture site with vertebroplasty or kyphoplasty.

27.1.5.3 Bertolotti's Syndrome

Bertolotti's syndrome (BS) consists on the presence of a transition vertebra that will cause a conflict due to a hyperplastic transverse process with the sacrum or the ilium or even in changes in the mobility of the lumbar spine that can trigger symptomatic discopathies, leading also to LBP. It affects 3–9% of the population and sometimes can be confused with spondylolysis.

Treatment consists of pain management and control, which can be attainable with rest and/or an orthosis. The role of physical rehabilitation is also important, not neglecting the sport-specific skills, in this case handball. Surgical treatment is not advisable [40].

27.1.5.4 Tumours, Infections and Inflammatory Conditions

These conditions are rare in the athlete but should be suspected when red flags are present in the clinical history, such as nonmechanical pain, night pain or constitutional symptoms (loss of weight, poor appetite or cachexia). Identification of the condition is generally difficult and requires a high level of suspicion. A delay often occurs between the first symptoms and diagnosis [40].

Benign spine tumours occur in children and adolescent players and include osteoid osteoma, osteoblastoma and aneurysmal bone cysts. Malignant primary neoplasms are osteosarcoma and Ewing's sarcoma. Malignant metastatic lesions are more common in adults as opposed to primary spine tumours. Leukaemia and lymphoma can be suspected in both adolescent and adult athletes [40].

Discitis is more common in the paediatric athlete than the adult one. Adult athletes are susceptible to vertebral osteomyelitis and soft tissue abscesses [40].

The primary inflammatory diseases that most affect the spine are spondyloarthropathies. This condition often starts at adolescence and can affect the spine, hips, knees and feet. It is important to obtain the diagnosis as soon as possible, since nowadays there is specific medication available that allows changing the natural history of the disease and thus its progression.

The clinician should ask four questions to suspected patients [41, 42]: (1) Does the morning back stiffness last over 30 min?, (2) Does the back pain awaken the patient during the second period of sleep?, (3) Does the pain alternate from one buttock to the other? and (4) Does rest relieve the pain? If two out of these four questions are positive, there is a 70% sensitivity and 81% specificity for inflammatory back pain [41]. History is much more accurate than laboratory testing in diagnosing inflammatory conditions. C-reactive protein has 50% sensitivity and 70% specificity in spondyloarthropathies. HLA-B27 has high positivity in the healthy general population [43].

The approach to these causes of low back pain should be multidisciplinary so that the best follow-up is given to the patients.

27.1.6 Non-Orthopaedic Causes of Low Back Pain

It is important that the clinician does not neglect other causes of low back pain when the diagnosis is not evident. Renal, pancreatic, bowel or reproductive organ disorders can cause LBP and should not be neglected.

Conclusion

The approach to back pain in an athlete can be a challenge. In most cases the cause is easily detectable as well as the treatment. However a great index of suspicion is necessary for more serious pathologies which could jeopardize the athlete's health and career. The literature is lacking on the subject of back pain and back disorders in athletes in general and handball players in particular, and it is therefore difficult to assess the true prevalence of low back pain in these populations due to the resilience of high competition athletes who always want to play so they do not lose their place in the team.

As handball is a contact sport, with sudden changes of direction and speed, overload injuries will be the most common. However the clinician should be alert to red and yellow warning flags so as not to neglect more serious pathologies.

Most of the conditions that give rise to LBP are treated conservatively, with surgery being reserved for more severe cases or when conservative treatment fails.

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Osteoarthritis in Handball Players

28

András Tállay, Romain Seil, and Lior Laver

28.1 Problem Overview: Frequency of Injuries

Team handball has been an Olympic sport since 1972. In Europe, it is one of the most popular team sports, after soccer and basketball. By July 2009, the International Handball Federation (IHF) listed 166 member federations with approximately 795,000 teams and 19 million players. According to the ranking of "TOTAL SPORTEK" based on 13 different factors, handball is the 22nd most popular sport all over the world but is one of the most popular team sports in Europe. Just within the last 3 years, the number of players doubled in some countries (e.g., Hungary 2015–2017, 31, 000 to 63, 000 registered handball players).

During the last decades, our game went through several changes: the court got smaller, but the game became much faster. The changes in the conditions and the rules and the increasing number of handball players unfortunately result in more and more traumatic and overuse injuries. Handball is a contact, pivoting sport. It involves lots of running, turning, and jumping during the game, causing high levels of mechanical stress to the knee joint. The vigorous nature of the ball game predisposes handball players to develop osteoarthritic changes in the knee, including, for example, cartilage damage, meniscus tear, ligamentous damage, and bone marrow edema-like lesions [1]. Handball is still one of the team sports where players are mostly affected by injuries. In comparison to other sports, it can be found in the top five in terms of number and gravity of injuries. At the professional level, matches are played year-round with elite players playing between 70 and 100 matches a year [2]. Concussions are not rare, as are acute joint injuries, mostly of the knee and ankle. The rate of ACL injury in handball has been recorded as high as 0.84 injuries per 1000 h of exposure, while the rate for women is even higher, with up to 1.82 injuries per 1000 h of exposure [3]. Seil found in another study the injury incidence in a male senior division at 2.5 injuries per 1000 player-hours, with a significantly higher

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incidence in game injuries (14.3 injuries per 1000 game-hours) compared with practice injuries (0.6 injuries per 1000 practice-hours) [4]. With the growing number of matches played every year, the risk of injuries is increasing, not only among elite adult players but in adolescents as well.

A major problem is the large number of young players affected by serious ligament injuries. Because many of the players suffer injuries at the very beginning of their handball career, on longer term it will result in early degenerative changes and osteoarthritis (OA). The current attitude of necessity to return to the pre-injury level results in sentences from the surgeons like "In terms of his/her career, he has a good chance of performing fine, but He'll have a much higher incidence of arthritis as he gets older than you or I would."

There's no question that handball is a good sport for children and adolescents. But the trauma associated with some youth sports can dramatically increase the risk that those young players will develop knee or ankle osteoarthritis by the time they reach adulthood. Participating in youth sports has many benefits; however, there are important health risks that should be considered, particularly the risk of joint injury and subsequent development of osteoarthritis, especially on elite level [5].

The large number of handball injuries is one of the main topics in different relevant journals and at different congresses (ESSKA, ISAKOS, KSSTA). Searching the PubMed database, just for "handball," there are 793 articles listed; interestingly for "handball and osteoarthritis," there are only 7. Despite some of the existing quality research based on handball players, the sport is lagging behind when it comes to producing evidence-based medicine and science. This is accentuated when looking at the evidence in handball medicine and science in the literature compared to other sports. The number of publications about the medical issues of handball is disappointing compared to around 9000 publications on football and over 3000 on basketball and volleyball. These findings are far from being correlated with the demands and popularity of the sport around the world [3].

Few data on injury registries are published in the literature; some of those are statistics of national registries, and others contain surveillance data of international tournaments. In a study from Sweden, Aman et al. found in a national injury database that large number and incidences of injuries as well as injuries leading to permanent medical impairment (PMI) (during 2008–2011 with each year approximately 12,000 injuries of 1,162,660 licensed athletes) were reported in football, ice hockey, floorball, and handball [6]. Giroto et al. in their study investigated the incidence and risk factors for handball injuries in 339 elite Brazilian handball players from 21 handball teams who participated in the two main Brazilian championships that were followed up during a season. In total, 312 injuries were reported by 201 athletes. The injury incidence rate during training was 3.7/1000 h and during matches was 20.3/1000 matches. The ankle (19.4%) and knee (13.5%) were the body regions most affected by traumatic injuries and the shoulders (44.0%) and knee (26.7%), by overuse injuries. This study showed that athletes with previous injury have shown a high risk of developing an overuse injury [7].

An injury and illness surveillance during the 24th Men's Handball World Championship 2015 in Qatar found that 27.1% of the players in total were injured, and of the 132 injuries reported, 40% were time-loss injuries. The total incidence of injuries was 104.5 per 1000 player-hours. The highest risk of injury was found among line players, and more injuries occurred during the first half of the matches. The most frequent injury location was the ankle, followed by the thigh, knee, and head/face. The majority of injuries were contusion, sprain, or strain. It has been concluded that the risk of injury in handball is high among Olympic sports [8].

As a sports orthopedic surgeon, how to deal with a 17-year-old player after revision ACL reconstruction who wants to continue handball on elite level, a 30-year-old handballer who has symptomatic articular cartilage wear but wants to continue with his/her competing, or a 40-year-old ex-handball player who is having trouble with her normal daily activities due to post-meniscectomy, ACL reconstruction, and osteoarthritis is a challenging problem. "Increasingly commonly, physicians are facing these management problems: younger, active patients who are developing osteoarthritis which is impinging on the activities that they want or need to do. Management of these patients is a major challenge and will always involve a balance between optimizing function and keeping expectations realistic. To be able to provide such patients with optimal advice and management, the physician or allied health professional needs to have a comprehensive knowledge of the condition, its natural history, the various treatment options available, and the evidence base for each [9]".

28.2 Problem Overview: Definition of Osteoarthritis

Our topic in this chapter is "osteoarthritis and handball." It is a challenging task to make a statement regarding which player has early or advanced osteoarthritis. OA is a leading cause of disability and the most common type of arthritis. Almost 59% (27 million) of the US population has arthritis or another rheumatic condition. Although OA generally affects older adults, injury-mediated OA has been observed in former athletes who are only in their early 30s and can be traced back to youth sports [5].

Searching the current literature, we can conclude that the term osteoarthritis is not clearly defined. The definition and classification of osteoarthritis vary on a wide range. Generally osteoarthritis (OA) is one of the most common causes of disability in adults. The prevalence increases with age, with a surprising 13.9% of the population over 25 years old and 33.6% of the population over 65 years old being affected [9].

Grading and classifications are most frequently based on radiographic imaging; advanced imaging, including whole-organ scoring; clinical symptoms, including stiffness, swelling, knee range of motion, and knee crepitus; and combination of symptoms and imaging. In addition to defining and classifying established arthritis, the following are more difficult to define:

1. How does one define "early arthritis"? If you have radiographic and/or imaging signs only, with no correlation to clinical symptoms or objective physical exam signs, is this arthritis? Should we define clinical (symptomatic) arthritis separate from radiographic (imaging) arthritis?
2. If there are focal defects, particularly focal defects on only one side of the joint, is this defined as arthritis?

Classification strategies for radiographic imaging have emphasized joint space narrowing, subchondral sclerosis, and osteophyte formation. By advanced imaging (MRI), the most common features that indicate osteoarthritis are cartilage thinning and subchondral bone edema. Whole-organ body imaging is largely being used as a research tool only. The struggle to define osteoarthritis is compounded when the clinician tries to define OA progression. One could define progression based on the classification strategies, i.e., change in radiographic markers (joint space narrowing, osteophyte formation, and/or axis deviation) and change in MRI imaging (increase in cartilage thinning, increase in subchondral bone edema).

The American College of Rheumatology radiological and clinical criteria for osteoarthritis of the knee are:

1. Knee pain for most days of previous month
2. Osteophytes at joint margins on radiographs
3. Synovial fluid typical of osteoarthritis (laboratory)
4. Age ≥40 years
5. Crepitus on active joint motion
6. Morning stiffness ≤30 min duration

According to this grading, knee osteoarthritis can be defined (clinical and radiographic) if 1 and 2; 1, 3, 5, and 6; or 1, 4, 5, and 6 are present.

This classification raises many questions in sports orthopedic surgeons; players with nearly no symptom but severe joint space narrowing and osteophytes on weight-bearing X-rays can be diagnosed with OA. In our experience, most of the asymptomatic active handball players have clear signs of OA on their X-rays 5–10 years after ACL reconstructions or meniscectomies. Interestingly, 40–50-year-old players, 20 years post-ACL reconstructions with obvious joint space narrowing and osteophyte formations on weight-bearing X-rays but with moderate daily pain levels, define themselves as healthy former players.

In conclusion, this chapter will not answer the question of OA definition and criteria. The used criteria for the definition of OA were not available in most of the later cited scientific studies; therefore, the comparison of the different clinical and statistical findings is not fully appropriate.

28.3 Osteoarthritis in Different Sports: A Comparison

Athletes, especially on elite level from different sports, are recognized as those that commit significant time to training and compete as either an individual or a team member at an international, highest national, or professional level. During their sports career, athletes are cumulatively exposed to high-energetic load and heavy physical demands. Those players are prone to suffering from musculoskeletal injuries. On long term the injuries of the different joints from the lower limbs result in the most significant osteoarthritis problems. These joint injuries might be recurrent and might need surgical interventions, frequently in combination with insufficient recovery time. OA has long been acknowledged as a potential adverse health problem in different types of sports.

Handball, a sport that rivals soccer for incidence of ACL injuries, perhaps not surprisingly also yields a high incidence of hip osteoarthritis, according to researchers from the University of Rouen in France. They reported 60% hip OA (in 12 of 20 male former elite handball players), compared to 13% of 39 age- and weight-matched male control subjects. And in another ACL-ravaging sport, volleyball, Swiss investigators found degenerative ankle disease in 19 of 22 former elite athletes but only 2 of 19 controls [1]. Despite the high prevalence of ankle injuries in handball, we couldn't find any validated data in the literature to compare the frequency of ankle OA with other sports.

The prevalence of OA in different sports was studied in Gouttebarge et al.'s systematic review. In four studies the prevalence of knee OA was ranging from 16 to 95% among former elite athletes from several disciplines such as endurance sports, team sports, power sports, table tennis, handball, and ice hockey players. They found a prevalence of hip OA ranging from 2 to 60% among former elite athletes from various disciplines such as long-distance runners, weight lifters, shooters, handball players, javelin throwers, high jumpers, football players, handball players, and ice hockey players [10].

Five studies presented a prevalence rate of generalized, lower limbs, or hip/knee OA, ranging from 1 to 59% among former players of Australian football, football league, and soccer. Only one study was retrieved in which OA in the upper limbs was explored, acknowledging a prevalence of shoulder OA (dominant arm) of 33% among former professional tennis players. With regard to the aforementioned, the prevalence of OA (joint of the lower limbs and shoulder) among former elite athletes from team and individual sports can be considered high when compared to the general population or employees from other occupational sectors. It remains doubtful whether the former elite athletes involved in the studies using self-report to determine the prevalence of OA might have been able to recall exactly whether they had been diagnosed with OA and at what age.

M L'Hermette et al.'s study clearly places intensive handball playing among other high-risk activities such as soccer (32%), fencing (35%), rugby, and tennis (16%). The type of sport, the length of time it has been practiced, and the playing level have all been suggested to contribute to the early appearance of hip OA. Indeed, this study was made up of players with a lower mean age (44.9) than normal for developing hip OA (55–70) [11].

28.4 Osteoarthritis in Handball

Despite the high prevalence of handball players that is widely studied and published, there are only limited available data in the literature about the incidence of OA of different body parts. While OA is generally thought to be a major public health problem that primarily affects the elderly, active or former handball players can have OA from a relatively younger age than persons who do not play handball or other demanding sports that result in mechanical stress to the locomotor system. In particular, trauma-induced damage of the cartilage, meniscus, and ligaments can trigger acceleration of degenerative OA-related changes within different joints, potentially leading to the need for arthroplasty at a relatively young age.

We performed a study to determine the prevalence of functional limitations and osteoarthritis in different joints, focusing on knee-related symptoms in Hungarian female national team handball players 10 years after winning an Olympic silver medal. Twenty-four female national team handball players participated in the 2000 Sydney Olympic Games. All players' anamnestic data for injuries were collected prospectively during the preparation for the Olympic Games. All players were physically examined, and athletes with previous knee or ankle surgeries have undergone standardized weight-bearing knee radiography. Self-administered patient questionnaires were taken (the Knee Injury and Osteoarthritis Outcome Score questionnaire) and all athletes were examined by two senior orthopedic sports surgeons, 10 years after elite sports. Of the available cohort of 24 female players, the following orthopedic procedures were done: knee surgeries, 23 (ACL repair: 9); ankle ligament reconstruction, 10; hand + finger ligament surgeries, 5; elbow, 1; and shoulder stabilization, 1.

By the end of the 10-year study period, 20 (75%) answered the questionnaires, 1 player died in car accident, and 3 were lost for the study. Fifty percent consented to undergo knee and 25% ankle radiography.

The mean age at assessment was 26.25 years; the mean sports age was 13 years by the start of our study. The mean weight was 67.7 kg and height 176.8 cm. Our players have 30–60 training days together, daily 2–3 trainings, up to 6 training hours daily. In team handball elite players had 20–25 national level plus 50 games in their clubs/year.

All female athletes with any lower limb surgeries in the past had radiographic changes in their index knee, and 18 (75%) fulfilled the criteria for radiographic knee OA. Answering the self-administered questionnaires, 18 (75%) reported having severe symptoms affecting their knee-related quality of life. More than 50% of the players had undergone reconstructive surgery or debridement in the study period. A very high prevalence of functional limitations, pain, and radiographic knee OA was observed in this young female population, of which majority have undergone different orthopedic surgeries in the whole duration of their handball career. Retrospectively, upon evaluating the post-op X-rays, we found that in many cases, the tunnel placement in ACL reconstructions 15–20 years ago was far from the more anatomical positions used nowadays (Fig. 28.1).

Our findings support the theories of the necessity of preventive training in handball. Players must be aware of early osteoarthritis of the lower limb after knee and ankle reconstructions in the early period of their sporting career [12].

28.4.1 Hip

Hip OA is a major cause of disability in the elderly, affecting up to 25% of the European white population over the age of 55. In addition to aging, the incidence of hip OA may be increased by a number of other risk factors including hip or acetabular dysplasia, genetic factors, occupational workloads, joint injuries, and anthropometric factors such as body mass index (BMI) [11]. If all the etiological factors are taken into consideration, idiopathic coxarthrosis is less prevalent than formerly. Three factors are new or reappraised: the first of them is sport practice (more than 10 years in competition) [13]. This is particularly true for sports involving traumatic loading such as handball, soccer, and basketball. Studies have shown that handball players have an increased risk of developing OA of the hip in the long term. This is surprising because hip pathologies are rarely reported in handball, although probably underdiagnosed [3]. In the French study of former handball players, none of the study subjects had a history of lower extremity injury, yet 60% had radiographic OA in at least one hip joint [1]. Jonathan et al. investigated the association between certain high-impact sporting activities and the risk of developing hip OA in elite athletes by conducting a systematic review of the available literature. Handball was associated with the highest rate of OA of any sport, nearly five times that of matched controls. Currently available literature suggests that male athletes participating in elite, high-impact sports (soccer, handball, track and field, or hockey) are at an increased risk of developing hip OA. They

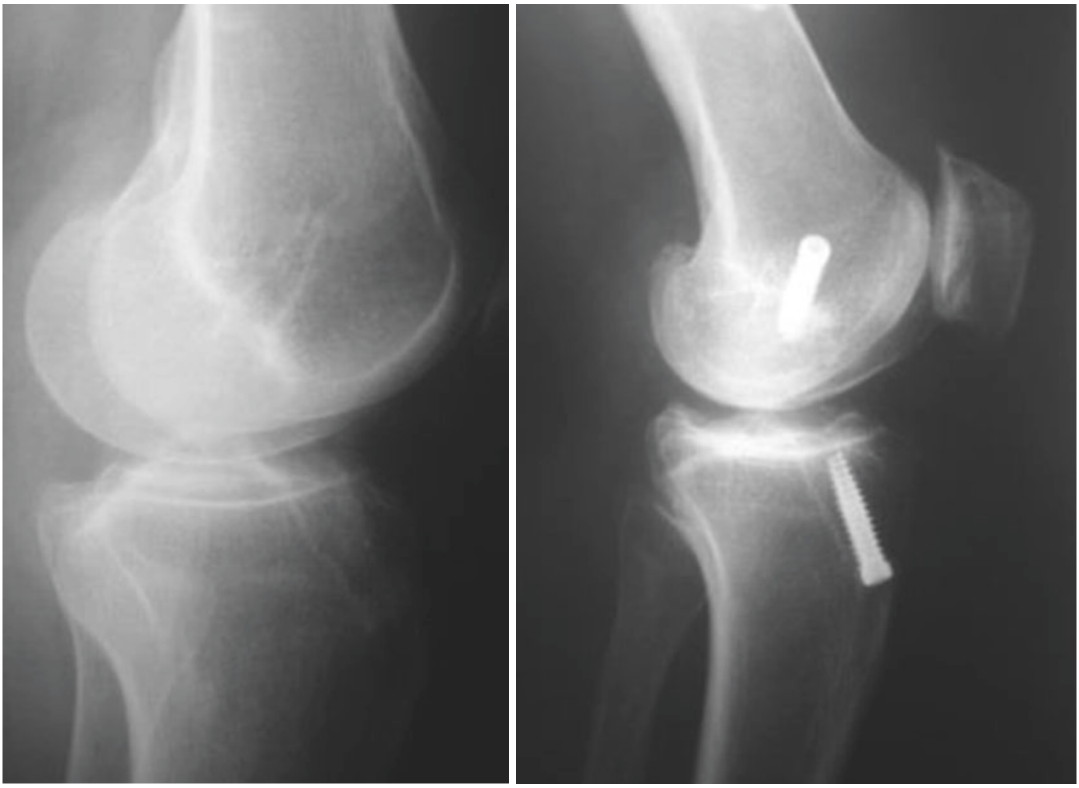

Fig. 28.1 Too ventral femoral tunnel placement in former elite handball players

concluded that further research is warranted to elucidate the pathomechanics of the development of hip OA in these patients [14].

Long-term handball practice seems to have an effect on hip ROM and to be associated with the premature development of hip OA. This observation supports the concept that elite and intense handball training may contribute to the appearance of hip OA. The risk of undergoing total hip replacement is increased 4.5-fold after the age of 50 and is increased in handball players because the joint loading measured during play is above the physiological limits of cartilage.

Further researches are needed to assess the magnitude of these degenerative problems and to develop preventive strategies [3].

28.4.2 Knee

The onset of knee OA is influenced by several factors; one of the most significant among those is a former sporting injury. Even in normal population in the USA, 14% of adults aged 26 years and older and approximately 33% of persons older than 63 years have radiographic evidence of knee OA. By the age 85 years, nearly half of all adults (46%) are expected to develop symptomatic knee OA [5].The injuries of the different structures—ACL, meniscus, and articular cartilage—of the knee are closely linked to knee OA. In a prospective study of young adults (1321 students with a mean age of 22 years at baseline), the risk of self-reported knee OA later in life was five times higher among those with a history of knee injury compared with those without injury (relative risk = 5.17, 95%, CI = 3.07–8.71, over a median follow-up of 36 years). Forty-seven men reported knee injury during adolescence or young adulthood (mean age, 16 years), and among those, nearly one-third (*n* = 15) reported that the injury was sports related. By age 65 years, the cumulative incidence of knee OA was 13.9% in participants who had a knee injury during adolescence or young adulthood and 6% in those without [5].

28.4.3 Meniscus

The removal of part or the entire load-bearing meniscus is also associated with knee OA. Meniscectomy is a significant risk factor for knee OA—the relative risk after total meniscectomy is six times greater than for unoperated controls. In a prospective study of ACL-injured patients followed for 15 years, the primary risk factor for tibiofemoral OA was a prior meniscectomy [15].

In a review of 41 studies of surgically treated and isolated meniscus tears (mean age 30 years, with adolescents included in some studies), radiographic knee OA was present in approximately 50% of those who had undergone meniscectomy 10–20 years earlier. In the long-term follow-up of young athletes undergoing meniscus surgery, more than 50% developed knee OA with accompanying pain and physical decline. These epidemiologic studies are supported by evidence from animal models of ACL/meniscus injury and OA development [5]. In the PubMed database, the search for “handball” and “meniscus” listed only five articles. None of them studied the adverse effects of meniscus resections. No specific data exists in the literature regarding the prevalence of OA in knees after meniscectomies in handball players.

Figure 28.2 illustrates the knee joint of a 45-year-old Olympic silver medalist. She had a subtotal lateral meniscectomy at the age of 20. She still plays in the second division and has only mild to moderate pain, despite her ROM being 20–90. She is aware of her severe OA, but retrospectively she is still confident with her decision in continuing her sports career after her primary surgery.

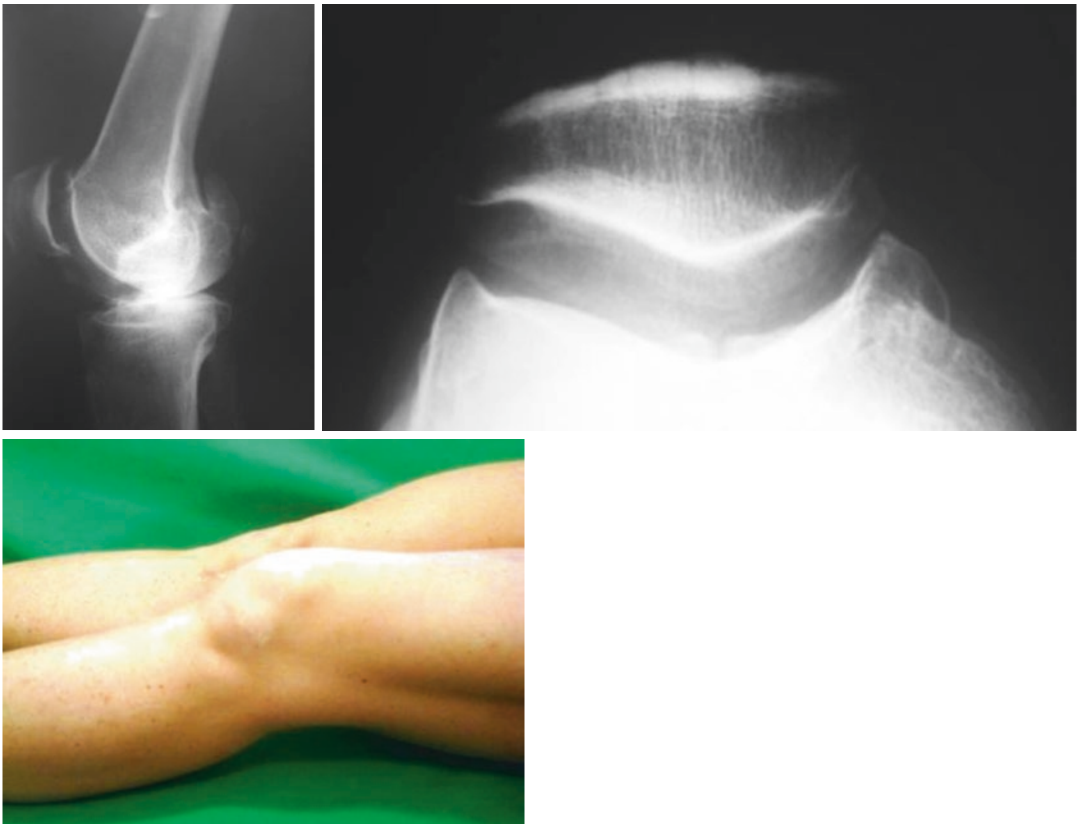

Fig. 28.2 Knee OA and limited ROM with a flexion contracture 20 years after lateral meniscectomy in a 45-year-old former elite player

28.4.4 ACL

Confirming the adverse effects of handball, a recent large-scale European research study involving 15,783 athletes who had primary unilateral anterior cruciate ligament reconstruction showed that male team handball players ($n = 1392$) had an increased risk of full-thickness cartilage damage compared to male team football (soccer) players ($n = 6473$). Another epidemiologic study demonstrated that playing handball was associated with symptomatic knee osteoarthritis (OA) in 295 men aged 25–70 who present to orthopedic clinics. Myklebust et al. studied the radiological long-term outcome after ACLR; they found that in the operatively treated group, 11 (42%) had developed radiological gonarthrosis, compared with 6 (46%) in the nonoperatively treated group. There was no correlation between radiological findings and pain scores [16]. Their results, particularly the high re-rupture rate, indicate that a more restrictive attitude on the return to competitive pivoting sports like handball may be warranted especially in younger age group, where the chance for a re-rupture within the first post-op year is up to 25%. Paschos NK, in his study, concluded [17] that ACL injury is a traumatic event that can lead to significant functional impairment and inability to participate in high-level sports-related activities. Evidence from the literature is controversial regarding the effectiveness of ACL reconstruction in preventing the development of knee cartilage degeneration.

Røtterud et al.'s study was undertaken to evaluate risk factors for full-thickness articular cartilage lesions in anterior cruciate ligament-injured knees, in particular the role of gender and the sport causing the initial injury. They concluded that male gender is associated with an increased risk of full-thickness articular cartilage lesions in anterior cruciate ligament-injured knees. Male team handball players had an increased risk of full-thickness lesions. No other sports investigated were found to have significant effect on the risk in either gender. Furthermore, age, previous surgery, and the time from injury to surgery exceeding 12 months are risk factors for full-thickness cartilage lesions [18].

A high incidence of ACL injuries has been reported in handball, but there is limited information on whether players are able to come back to their pre-injury sport level after an ACL injury. A major long-term problem after an ACL injury—independently, whether the treatment is operative or nonoperative—is OA to the knee. It must be taken into consideration as a parent, coach, sports physician, or operating surgeon when a young player suffers a serious ligament injury and asks for an opinion whether he/she is advised to continue playing handball on elite level or not. In our study we found that the earlier ACLR techniques were far from the more anatomic technique that is currently used; therefore, there is hope for less chance of early OA in the future for the handball players with our more recent anatomic techniques.

28.4.5 Ankle

Knowledge of the biomechanics of the foot and ankle joints is essential for understanding related handball injuries. The major cause of ligamentous ankle lesions in elite handball players involves plantarflexed and inversion ankle movements. Due to the decreased stability in that postural position, and due to sport-specific cutting actions, severe inversion/eversion injuries can occur. When chronic lateral ankle instability occurs (following repeated episodes of ankle sprains) and/or when functional rehabilitation fails, surgery is required. If the treatment of instability, talus OCD, or ventral/dorsal impingement fails, there is a high chance for OA [19].

Reports indicate that ankle OA affects 1–4% of adults. Among 500 consecutive patients in the United Kingdom with OA, the ankle was the fourth most common site for OA after the knee, hand, and hip. Ankle OA has been reported to occur most often as a result of trauma and is associated with chronic ankle instability [5]. Population-based prospective studies of ankle injury and OA are lacking, but clinical observations suggest that many cases of ankle OA are posttraumatic and sport related. Medical chart data of 30 patients with ligamentous posttraumatic OA, who were referred to an ankle arthritis center, revealed that 55% of ankles with OA (18 of 33 ankles) were sprained during sport (mean age of athletes, 24 years, range 15–38 years), and 39% (7 of 18 ankles) of these injuries occurred between the ages of 15 and 19 years. Although not specific to youth sports, the prevalence of ankle OA in 2552 retired football players was 2.3 times greater in those who had experienced at least one ankle sprain during their professional careers compared with those who did not [5]. Despite the high incidence and prevalence of ankle injuries, the prevalence of OA in the ankle among former handball players hasn't been studied yet. In our experiences, similar with severe knee injuries, suffering a major ankle injury at the early period of the sporting career will result in joint OA. Figure 28.3 shows the ankle of a former elite player, who suffered an open ankle dislocation in 1995. The signs of arthritis are clearly visible on her X-ray 15 years after the injury. Again, she is aware of her severe OA, but retrospectively she is still confident with her decision in continuing her sports career after her primary surgery.

28.4.6 Shoulder

OA in the glenohumeral joint is not a significant problem in handball, but there is a growing interest in the role of shoulder overloading and its effect on the type and occurrence of the injury. Early data suggested that during a season, 66% of players at a high amateur level develop overuse-related symptoms, and this has been confirmed in later years. The shoulder joint is the joint most affected by overuse injuries. This is not surprising since a player performs approximately 50,000 throws per season in high-level handball. As a consequence, the prevalence of structural abnormalities in the shoulder has been reported to be as high as 93% after an average professional practice of 9 years [3].

Møller et al. investigated if an increase in handball load is associated with increased shoulder injury rates compared with a minor increase or decrease and if an association is influenced by scapular control, isometric shoulder strength, or glenohumeral range of motion (ROM) among adolescent 679 players. They found that a large increase in weekly handball load also increases the shoulder injury rate in elite youth handball players, particularly in the

Fig. 28.3 Ankle OA and limited ROM 15 years after a former elite player suffered an open dislocation

presence of reduced external rotational strength or scapular dyskinesis [20].

Despite the published data on high risks of acute and overuse shoulder injuries, we were not able to find precise data on the long-term effects of these structural lesions in terms of the prevalence of glenohumeral osteoarthritis (OA) among handball players.

28.4.7 Elbow

Searching in PubMed for scientific data on the prevalence of elbow OA in handball resulted in 0 documents.

The goalkeepers are the ones usually affected by elbow injuries in handball. It is mostly caused by ball impact during blocks which allow the exposure of the elbow joint to repetitive traumas in hyperextension position.

Matheus et al. published a systematic review paper on the "Handball goalie's elbow syndrome." A database search was conducted in MEDLINE via PubMed, Embase, SPORTDiscus, and LILACS. The quality of studies included was assessed using a modified and adapted checklist. The search results identify a total of 623 papers, and only 10 articles were included in our review. The results of included articles demonstrated that handball elbow injuries have a high incidence, and the mechanism of this injury is repetitive traumas in elbow hyperextension by ball contact with the forearm region [21].

28.4.8 Spine

The number of handball players suffering from thoracic or low back pain (LBP) is increasing, but similarly as with other joints (shoulder and elbow), no data on the prevalence of spondylarthrosis among former handball players exists. There are studies supporting the high prevalence of LBP in handball; other studies found that the prevalence of LBP in handball players doesn't differ from those in other sports or normal population. There are several former elite players having no or moderate LBP despite severe arthritis changes on the X-ray (Fig. 28.4). Triki et al. examined the prevalence of low back pain (LBP) in a Tunisian sports and physical education institute. A total of 3379 boys and 2579 girls were studied, and a retrospective cross-sectional survey was conducted on a group of students aged 18.5–24.5 years. They found that LBP is frequent among undergraduate students, and it is strongly associated with fatigue after long periods of training. It has been identified that gymnastics, judo, handball, and volleyball pose high risk of LBP [22].

Fig. 28.4 35 years old nearly asymptomatic former handball player, with severe OA sign on the X-ray

Using a questionnaire, *Tunås P* et al., in their cross-sectional study, compared the prevalence of low back pain (LBP) between female elite football ($n = 277$) and handball ($n = 190$) players and a randomly selected nonprofessional active control group from the Norwegian population ($n = 167$). 57% percent of the football players, 59% of the handball players, and 60% of the control group had experienced LBP in the previous year. There were no significant group differences in the prevalence of LBP ever ($p = 0.62$), the previous year ($p = 0.85$), or the previous 7 days ($p = 0.63$). For both sports, there was a significant increase in the prevalence of LBP from the resting period to the competitive periods of the season ($p \leq 0.001$). Seventy percent of the goalkeepers in both football and handball had experienced LBP in the previous year. There was no difference in LBP among female elite football and handball players compared with the control group. However, female elite athletes in football and handball reported a higher prevalence of LBP compared to the previous studies. The variations in LBP and playing positions indicate that specific field positions, in football and handball, are a risk factor for developing LBP, but the long-term effects were not studied [23].

28.4.9 Treatment of OA

It is extremely difficult to treat OA in any patient; managing OA in a former elite athlete is a real challenge. Once OA develops in the post-athlete phase, it’s a difficult clinical problem; therefore, the optimal way to minimize the risk of OA is to prevent the initial injury. The currently available usual OA therapies—including bracing, orthoses, weight management, chondroprotection, viscosupplementation, and physiotherapy—should be used by former athletes as well. After a joint injury, handball players should be educated immediately that there are things that can be done to prevent arthritis, and they should be encouraged to seek proper diagnosis, treatment, and interventions as soon as possible. After all conservative and less-invasive treatment options have failed, there is the final question of joint replacement surgery. Young former handball players with badly damaged joint are frequently trying to use any other options to avoid temporary joint replacement surgeries. In some cases a reconstructive surgery and/or osteotomy that can restore stability and relieve pain by helping to correct joint alignment may be an alternative. For active, middle-aged former players, we also use more aggressive arthroscopy to “clean up” the joint.

The more difficult question involves treatment of the injured athlete, whose risk is already elevated. With further research, biomechanical analysis may be able to identify those athletes who cannot withstand high-impact loading following an injury. Studying the genetics of OA is essential, because the possibility is rising that eventually an athlete will have the advantage of knowing whether he or she is genetically predisposed to OA before choosing a sport. Probably in the future, we will know who has a higher risk of developing primary OA, and those with very high familiar risk should perhaps not participate in sports like handball.

28.4.10 Prevention of OA

The real issue may be getting athletes, especially young athletes, to think realistically about a high chance for osteoarthritis as a consequence of sports-related injury.

The first step to avoid early OA is the primary prevention: according to our experience and RCTs, it is possible to prevent a substantial number of sports injuries. Studies over the past decade have identified new and modifiable risk factors for sports injuries and mechanisms of injury and provided evidence from multiple interventional, prospective, longitudinal studies and randomized controlled trials of how these factors can be modified.

Once a joint is significantly injured, the incidence of eventual knee OA dramatically increases. It poses a challenge for the clinician and those involved in injury prevention to devise a secondary prevention strategy. There is a reason to be cautiously optimistic that this is possible. Surgical treatment after different types of injuries—like reconstruction of the ACL—restores short-term function and has good patient-reported outcomes but does not prevent knee

OA. Similarly, exercise therapy and neuromuscular training are theoretically beneficial and common treatments for sports injuries; their efficacy in treating handball injuries and preventing OA and the superiority of one form of exercise intervention over another are not supported by high-quality trials. Because of the uncertain results of widely used preventive measures, prevention of OA in handball players may start with the young. The identification of adolescents with early knee injury and those with potential neuromuscular and other risk factors might permit targeting of at-risk groups for playing handball, activity modification, and education that may have an impact on the prevention of knee OA.

Adhering to the model introduced by van Mechelen, proper epidemiologic data are necessary to identify risk factors associated with injuries, implement prevention programs, and re-evaluate their efficiency [15].

Fact Box

Ex-elite handball players have a higher prevalence of premature osteoarthritis of the hip and knee than age-matched controls. They show limited passive range of motion and higher pain level specific to the long-term practice of handball.

The risk of OA after severe lower limb injuries in young handball players is extremely high.

Conclusion

The recent scientific literature with regard to the definition and assessment of OA is heterogeneous. The present chapter has suggested that the prevalence of OA, especially in the joints of the lower limbs, is high in former handball players compared to the general population. More accurate research—more comparable data, clear description of OA criteria—in larger handball players cohort study population concerning the onset of OA in all joints should be conducted. An international injury register of severe and/or recurrent joint injuries during a sports career might enable athletes at risk of an early onset of OA to be identified. Health professionals working with young handball players should counsel them and their families on the benefits and risks associated with sporting activity, including the possible long-term risk of OA. Physical activity in younger age should be vigorous (but not excessive in frequency, intensity, or duration) to promote healthy joint development. Assessments (i.e., medical examination and screening) prior to sport participation should be performed to identify children and adolescents at high risk for injury or joint problems [5]. There is a lack of consistent and continuous epidemiologic data research which is necessary to properly follow the van Mechelen model and improve the players' safety in an ever changing sport environment.

In this case, a post-injury and probably an end-career health consultation, in combination with a self-management intervention, could be implemented for athletes in the period around their retirement from sport, which aims to empower their future health and functioning in their post-sport life.

ESSKA's mission is to raise the level of care and achieve excellence in the field of orthopedics in Europe, especially in sports medicine and degenerative joint diseases. In some years from now, it can be expected that the medical aspects around handball will be as thoroughly organized as in football and that the science emerging from this improved structure will be beneficial for both the sport and the players' health in the short and long run [3].

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Part IV

Prevention, Rehabilitation and Preparation

29

Injury Prevention in Handball

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Injuries are a significant problem in many sports, and handball is no exception. It is a rough intense contact sport, involving sprints, cutting movements, jumps and landings, pivoting and repeated accelerations and deceleration movements. A serious consideration in the long-time fate of injured joints is early joint degeneration. With this in mind, primary injury prevention is even more important.

Handball epidemiological studies have shown that both acute and overuse injuries are a major concern. Knowledge regarding prevention of especially acute lower extremity injuries in handball has improved substantially in the last 10–15 years. We know more about how the injury happens, who is injured and, most importantly, how these injuries can be prevented. Positively, we know that we can reduce the risk of having an acute lower extremity injury, including ACL injuries, by 50% by implementing injury prevention exercise programmes (IPEPs) as structured warm-up programme on regular basis in handball [1, 2].

Overuse injuries in handball is a well-known problem, though the knowledge on how we can reduce the risk of overuse injuries is sparse. However, a recently published paper has shown that it is possible to reduce the risk of shoulder overuse injuries in handball by 28 % by performing a set of exercises during the warm-up [3].

This chapter will present the available knowledge on prevention of handball injuries. Based on the available scientific literature, it will deal with prevention of acute lower extremity injuries, especially ACL injuries and overuse shoulder injuries.

29.1 Lower Extremity Injuries

Among team sports, handball is one of the sport disciplines with the highest injury risk. Thus, handball has the highest risk of injury in all body locations, regardless of gender [4]. Recent data from a large-scale insurance registry has shown that handball is the team sport with the highest risk of injuries leading to permanent medical impairment in Sweden [4]. Lower extremity injuries and especially ACL injuries are a major health concern among athletes participating in handball.

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29.1.1 Injury Pattern and Incidence

The most common injuries in handball are knee and ankle injuries representing almost 48% of all traumatic injuries [5]. According to a recent Danish survey, approximately half of all injuries cause absence from handball activities more than 1 week, and the weekly mean injury prevalence has been reported to be as high as 21% [5].

One of the most serious lower extremity injuries is an ACL rupture. The risk of sustaining an ACL injury is much higher in matches compared to training, perhaps as much as 30 times higher [6]. The exact reasons for this are not known, although it's probably safe to assume that it is related to the intensity of play.

29.1.2 ACL Injury Mechanisms

In sports medicine science, the ACL injury has been one of the most examined lower extremity injuries. Most ACL injuries in handball are non-contact in nature; approximately 90% of injuries occur without contact with an opponent [6, 7]. Of the two main injury mechanisms, approximately 90% of injuries occur when the player performs a cutting or pivoting movement or in a one-legged landing after a jump. Even if there is no direct player contact to the knee, some perturbation by opponent interaction can sometimes be observed before the injury.

The mechanisms for non-contact ACL injuries have been widely discussed. What seems clear from several studies from various team sports is that knee valgus (high knee abduction moments), where the knee collapses inwards into a "'knock-knee'" position, is an important factor.

Kristianslund et al. [8] analysed the cutting technique among 123 of Norway's best female handball players. They aimed to identify which cutting technique resulted in the lowest knee abduction moment. High knee abduction moments, or valgus moments, may increase the risk of ACL injuries, and training of techniques that reduce knee abduction moments is likely beneficial for reducing the ACL injury risk. The players performed sidestep cuts in a biomechanics lab, which enabled accurate descriptions of joint movements and loading. The technique was described with 12 factors including knee valgus, hip abduction, toe landing, approach speed, cutting angle and cut width. The results showed that sidestep cutting technique explained 62% of the variance in knee abduction moments. Sidestep cuts performed with high knee valgus, heel landing and wide stance resulted in higher knee abduction moments [6]. This study confirms that technique factors are strongly related to lower knee abduction moments. This high-loading technique is similar to descriptions of the injury mechanism. When analysing cutting injury situations, the injury often occurs with a valgus collapse in wide cuts with a heel landing.

The study by Kristianslund et al. confirms that the frequently used catch phrase in prevention programmes, "keeping the knee-over-the-toes position", seems justifiable and should be continued to be used. In addition, it also emphasises the importance of teaching young players to perform a narrower cut. Technique training that reduces the knee valgus moment should include a focus on toe landings, a knee-over-toe position and narrow cuts (Figs. 29.1 and 29.2).

Another key component is understanding how the handball player is able to recruit the hamstring muscles during high-risk movements such as side cutting. Danish research has found that low activation of especially the medial hamstring increases the risk for a future ACL injury [9]. This emphasises the importance of implementing exercises that target the hamstring muscles activation in order to optimise the neuromuscular pattern during, e.g. narrow cuts.

A key identified external risk factor is high friction between handball shoes and the playing surface. Handball is played on different floor types with varying friction characteristics and shock-absorbing ability. Floors are usually of two types: parquet (wooden floor) or artificial floors. One study has shown that the risk of ACL injury is 2.4 times greater when competing on artificial floors (with an increased coefficient of friction) compared with wooden floors [10]. However, we must keep in mind that the new artificial floors have evolved over the last years; hence new studies are advisable. In any case, based on existing data, it seems

Fig. 29.1 A more narrow cutting technique (preferred)

Fig. 29.2 A wide cutting technique (higher ACL injury risk)

reasonable to suggest that players should have at least two different pairs of shoes: a more "slippery" pair suitable for high-friction floors and another pair with more traction for slippery floors.

29.1.2.1 Who Is Injured?

In handball, several factors have been associated with an increased risk of sustaining lower extremity injuries.

29.1.3 Gender

A key question has been whether female players are at greater risk than males? The first study on this was published in 1990 [11]. The ACL injury incidence was highest among elite female players with 0.82 ACL injuries per 1000 playing hours compared to males with 0.31 injuries per 1000 playing hours [11]. This gender difference has later been confirmed by Myklebust et al. [6, 7]. The highest ACL incidence reported is among elite female handball players in Norway with 2.29 ACL injuries per 1000 match hours [12].

Thus, the gender difference is apparent when analysing ACL injury risk in handball. However, the reasons for the obvious gender gap in the risk of ACL injury are not completely clear. Various researchers have suggested differences in anatomy, hormonal and neuromuscular function as potential reasons for the higher injury risk in women than in men. To date, however, there is little evidence linking all these potential intrinsic risk factors to non-contact ACL injuries, and a great deal of controversy exists on the relative importance of the different factors. However, it is noteworthy that the only modifiable risk factor is the neuromuscular function why prevention of injuries in handball is equivalent with the concept *neuromuscular training*.

29.1.3.1 Age

Most ACL injuries occur in players in their late teens and early 20s. Especially, adolescent females (aged 14–19 years) are at high risk of sustaining an ACL injury [13]. Unfortunately, latest data from national ACL registries in Scandinavia has shown that ACL injuries among young female players have increased (Lars Engebretsen, personal communication).

A recent meta-analysis revealed an age-related association between prevention and reduction of ACL incidence. Both biomechanical and epidemiological data indicate that the potential window of opportunity for optimised ACL injury risk reduction may be during early adolescence [14].

29.1.3.2 Injury Prevention

Lower extremity injuries can be prevented! The evidence is strong—both lower extremity as well as ACL injuries can be prevented by neuromuscular training (NMT) [14]. The concept of NMT involves multiple exercise modalities such as muscle strengthening, balance/coordination, plyometric and core exercises, altogether aiming at increasing muscle strength and improving postural balance control and muscle coordination during high-risk movement conditions related to non-contact ACL injury. In recent meta-analyses, 14 clinical trials were identified, and the estimated effect of neuromuscular training was a reduction of approximately 50% in lower extremity injuries [14].

Of these clinical trials, three NMT interventions were examined among handball players. These are presented in details below.

29.1.4 Training Programmes

In a study by Myklebust et al. [12], a five-phase neuromuscular training programme was tried out among approximately 1000 female players in the top three divisions in Norwegian handball. The programme consisted of three different balance and strength exercises focusing on neuromuscular control and cutting and landing skills. The players were encouraged to be focused and conscious of the quality of their movements, with emphasis given to core stability and hip and knee position in relation to the foot (the "'knee-over-toe"' position). The intervention resulted in a substantial reduction in the risk of ACL injuries from the control season to the second intervention season among the elite players who completed the programme [12].

In the study by Petersen et al. 2005 [15], 10 female handball teams (134 players; 8 amateur teams and 2 from the 3rd highest league) took part in a prevention programme to prevent ankle and ACL injuries, while 10 control teams (142 players; matched for age and playing level) were instructed to train as usual. The programme consisted of:

1. Information about injury mechanism
2. Balance-board exercises
3. Jump training

They followed the teams over one season and achieved a non-significant reduction of ACL injuries with five vs. one ACL injuries in the control group compared to the intervention group [15].

A high-quality study design was used in the first randomised controlled trial in handball by Olsen et al. [2] among youth female and male players. They showed that a structured warm-up programme including running exercises with and without ball, technique training focusing on safe cutting movements, two-feet landings after jump shots, balance training and strength (including the Nordic hamstring exercise) and power exercises gave a highly significant reduction (50%) in the rate of acute lower extremity injuries among players in the intervention group. In this study the teams were highly compliant with the programme—87% of the teams performed the programme as intended. In addition, the sample size was high enough to detect a difference between the intervention and the control group.

A more recent randomised controlled study by Achenbach et al. [16] included 23 adolescent handball teams of both genders (U-18 and U-16), of which 13 teams were randomly allocated into an intervention group (168 players) and 10 teams into the control group (111 players) [16]. A handball-specific developed injury prevention programme consisted of two different sets of exercises. The programme included jump exercises, landing exercises, proprioceptive exercises, plyometric exercises as well as quadriceps, hamstring and core strengthening exercises. Each set comprised of five exercises which progressed in three steps by difficulty level. The programme consisted of 15 min training exercises 2–3 times per week during the 10- to 12-week preseason and of 15 min training exercises once per week during the competition period. The injury prevention programme was shown to significantly reduce the occurrence of severe knee injuries in the intervention group compared to the control group [16].

A video presentation of the prevention programme of the studies of Olsen et al. and Myklebust et al. are available at www.skadefri.no.

Despite the relatively sparse number of studies, we can conclude that it is possible to prevent severe knee injuries in handball—we can even reduce the risk of ACL and lower extremity injuries by 50%! Prevention studies from other team sports supports this conclusion [17–19]. However, it is yet to be known which of the factors that are positively influenced and which are the origin of the improvement; more studies are needed.

It is important to mention that proper supervision by a skilled person is essential when implementing an IPEP among handball players with no previous experience in this kind of training. In a study by Zebis et al. (unpublished), a markedly lower activation of the hamstring muscles was observed when complex exercises, like one-legged landing on unstable surface, were introduced by an app versus supervised by a skilled person (Zebis et al. personal communication/unpublished). We must keep in mind that most of these studies have been published in skilled players of a relatively high level. More studies on younger players and players at lower levels of play are needed.

Practical recommendations for implementation of injury prevention programmes are presented in a subsequent chapter in this book.

29.2 Shoulder Overuse Injuries: A Burden for Handball Players

Shoulder injuries, predominantly from overuse, have been reported to be common in handball and represents a substantial health burden for the players. Among amateurs, chronic shoulder pain has been reported as the most frequent overuse symptom [20]. At the elite level, approximately 50% of players will experience a shoulder problem during a season, and at any time, between 23 and 28% struggle with a shoulder problem affecting their performance and participation [21, 22]. Structural lesions in the throwing shoulder have been reported to be present in more than 90% of players with 9 years average duration of competition at the elite level [23]. In elite youth handball, the rate of new shoulder injuries during a season has been reported to be 1.4 per 1000 playing hours, with 51% classified as non-traumatic [24]. These numbers highlight the need for preventative efforts towards overuse shoulder injuries across different age groups and various competition levels in both genders.

29.2.1 Risk Factors

29.2.1.1 Glenohumeral ROM

Reduced internal rotation (IR) and increased external rotation (ER) have been reported in the dominant shoulder of asymptomatic handball players [22, 25, 26]. This is considered as a normal and possibly necessary soft tissue and bony adaptation among throwers and has even been suggested to prevent injuries [27, 28]. However, risk factor studies have reported associations between reduced IR and total ROM in the dominant arm and shoulder injury among handball players [22, 25, 29]. In contrast, increased IR has also been reported to have a limited association with increased risk [21]. These contradictory results make it difficult to neither recommend nor abandoned IR stretching as a part of injury prevention in general.

29.2.1.2 Glenohumeral Rotation Strength

Weakness in ER has been reported as a risk factor for overuse shoulder injuries among male elite handball players [22]. Recently, a study failed to confirm this finding in a mixed-sex cohort of elite handball players using similar methods [21]. Interestingly, both these studies mention non-significant trends in their data suggesting that lower ratios of ER to IR strength (ER:IR ratio) may be worth considering as a risk factor. A similar finding has been reported among elite youth handball players, where lower ER:IR ratios was associated with shoulder injuries [30]. In addition, it was recently reported that ER weakness exacerbated the association between handball load and shoulder injuries among elite youth handball players [24]. Considering the overall body of evidence from these studies, it seems reasonable to recommend handball players to perform exercises to strengthen ER when aiming to prevent overuse shoulder injuries.

29.2.1.3 Scapular Dyskinesis

Three prospective risk factor studies have investigated associations between scapular dyskinesis and shoulder injury in handball. Among elite male players, scapular dyskinesis has been reported to increase the probability of reporting shoulder problems during a season [22]. This association could not be replicated in a mixed-sex cohort of elite players using similar methods [21]. In contrast, among elite youth handball players, the presence of scapular dyskinesis has been reported to exacerbate the association between handball load and shoulder injury [24]. Despite contradictory results at the elite level, it seems reasonable to include exercises targeting scapular strength and/or control when aiming to prevent overuse shoulder injuries, as no negative associations have been reported.

29.2.1.4 Handball Load

Despite growing evidence highlighting rapid increase in load as an important risk factor for overall injury across a range of different sports, only one study has investigated this association in handball. Møller et al. (2017) [24] reported an association between large increase in weekly handball load and increased rate of shoulder injuries among elite youth players (read more about this in Chap. 43). In addition, scapular dyskinesis and ER weakness have been reported to reduce the amount of increase in load a player could tolerate before sustaining a shoulder injury. This supports implementing exercises targeting ER strength and scapular dyskinesis when aiming to prevent shoulder injuries.

29.2.2 Prevention

Recently the effect of an exercise programme, the Oslo Sports Trauma Research Center Shoulder Injury Prevention Programme (OSTRC SIPP), designed to reduce the prevalence of overuse shoulder injuries in elite handball was evaluated in a randomised controlled trial [3]. A total of 660 players were followed over the course of a season with prospective registration of shoulder problems. Compared to the control group, the prevalence of shoulder problems in the intervention group was substantially reduced, and the risk of reporting shoulder problems was 28% lower. Due to methodological limitations of the study, the preventative effect on specific structural lesions remains unknown. This should be addressed in future research to assess if and which lesions that can be prevented in the long term.

The programme used consisted of five exercises with different variations and levels, aiming at increasing glenohumeral IR, ER strength and scapular muscle strength, all identified risk factors for shoulder injury among elite handball players [22, 25, 30]. In addition, an expert panel

Fig. 29.3 “Eccentric brake with backwards throw” – a partner throws the ball from behind (A). Catch the ball (B) and throw it back using external rotation of the shoulder (C). Progress by using a weighted ball. (3 × 10-20 repetitions)

Fig. 29.4 “Slow arm lowering” – Pre-position the shoulder before initiating the exercise by lifting the chest and pulling the shoulder slightly back and down. Tighten the elastic with two hands to cocking position (position A) and slowly lower the arm with one hand (position B), three seconds. Progress by using an elastic band with increased resistance. (3 × 8-16 repetitions)

Fig. 29.5 “Push-up plus with backward slide” – lower the body from position A to position B, return to position A, continue to position C and return to position A and repeat. The push-up plus position is achieved by pushing the hands towards the floor and moving the shoulders forward and out. Progress by moving further back into position C. (3 × 8–16 repetitions)

suggested that exercises aiming to improve the kinetic chain and thoracic mobility should be included. The recommendation was to include the programme three times per week as a part of the team’s handball warm-up, with coaches and team captains as delivery agents. Once players were familiar with the exercises, the programme took about 10 min to complete. The complete programme is available as an online appendix in the original publication from Andersson et al. [3]. Examples of exercises included in the programme are illustrated in Figs. 29.3, 29.4 and 29.5 “Shoulder” 1–3, and videos of the exercises are available from www.ostrc.no.

29.2.2.1 Recommendations for the Handball Clinician

We recommend including prevention programmes like the OSTRC SIPP as a part of the warm-up routine in handball. However, for experienced clinicians working with handball players, we recommend using the principles of the programme and combine these with the advantage of interacting with players on a regular basis. Including variation and difficulty progression as well as seeking to make the programme a natural/adoptable part of the warm-up is also recommended. A key challenge when implementing injury prevention programmes will always be adherence. Despite the fact that the programme takes about 10 min to complete, the average adherence reported by Andersson et al. [3] was only 1.6 times per week, only 53% of the recommended three times per week. This questions the time consumption players and coaches are willing to invest and if it is possible to compress the programme. Based on the risk factor studies mentioned above, it seems reasonable to prioritise exercises targeting ER strength and scapular muscle strength when looking to compress the programme.

29.2.3 Coach as a Key Partner

Winning and performance are the key factors for coaches and players. Injured players will not improve their own or the team's performance. Coach education is a key factor. Well-trained coaches will be able to deliver a new exercise programme in the correct way. Knowledge of sports injuries, injury prevention, attitudes and beliefs around the importance of injury prevention training is quite variable among coaches.

Fact Box
Without doubt, injury prevention should be mandatory as part of coach education and certification at all levels.

29.2.4 How Can Handball Become a Safer Sport?

It is possible to prevent acute lower extremity injuries and shoulder overuse injuries by using neuromuscular training and a structured warm-up programme. However, lack of uptake and ongoing maintenance of such programmes is an ongoing concern. A focus on implementation is critical to influence knowledge, behaviour change and sustainability of evidence-informed injury prevention [31]. In addition, there are other aspects that should be kept in mind when trying to reduce the injury numbers.

The risk of suffering injuries may increase during championships when the best players are exposed to an abnormally high number of matches during a short time period. In planning championships, Olympic Games and other tournaments, it is important to allow an adequate number of days for the athlete to recover. Young players who participate at a high level have a clear tendency for participation on many teams and to compete at different age levels. This increases the number of matches/competition and reduces the time they have available for rest and training. Playing matches is a high-risk situation for all acute injuries and especially for ACL injuries. Every handball federation should be aware of this and try to protect young athletes from over-participation in sports.

As suggested above, players should have two different pairs of shoes: one for high- and one for low-friction floors. In addition, we must also keep in mind that cleaning and maintenance routines influence floor friction, regardless of floor type.

When children start playing handball, help them to develop good warm-up habits, fair play attitudes and teach them safe cutting and landing techniques. Young athletes are the greatest assets, and as such, the best coaches should be working with this population.

29.3 Fact Box

Key Points from a Validated Injury Prevention Exercise Program
A five-phase 15 min programme with three different balance exercises focusing on neuromuscular control and planting/landing skills.
Focus on proper hip-knee-toe control—"keeping the knee-over-the-toe position".
During an initial training period of at least 5 weeks, the exercise should be done a minimum of 3× per week, training for 10–15 min per session.

Maintenance training 1× or 2× a week should continue throughout the competitive season.

The programme can be incorporated into a warm-up session.

Ball or partner exercises to make training more challenging and fun.

Exercises include balance exercises on floor, balance board or on an unstable balance pad.

Exercises include strength elements, such as two- and one-legged squats.

Injury risk was significantly reduced for those players who highly complied with the exercises.

Recommended Key Points from a Validated Overuse Shoulder Injury Prevention Programme

Warm-up programme including exercises to improve glenohumeral internal rotation motion, external rotation strength, scapular muscle strength, the kinetic chain and thoracic mobility.

When seeking to compress the programme due to time consumption, focus on external rotation strength and scapular muscle strength.

Strive to include variation and progression (important for motivation).

Seek to make the programme a natural/adoptable part of the warm-up.

Include exercises in pairs to make training more fun.

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Implementing Handball Injury Prevention Exercise Programs: A Practical Guideline

30

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30.1 Introduction

As described in previous chapters, musculoskeletal injuries are common in handball and may be associated with significant treatment costs, participation loss, and long-term adverse side effects.

Several studies have demonstrated that a rapid increase in training load increases the risk of overall injury in a variety of sports including handball [1–3]. Load management is thus considered as an essential part of preventive initiatives. Unfortunately, there are currently no studies on the efficacy of load management in the form of a randomized controlled trial (RCT). Previous research has instead focused on primary prevention via injury prevention exercise programs (IPEPs). The focus of this chapter will, therefore, be on the implementing IPEPs in a "real-world" context.

The results of RCTs presented in the previous chapter demonstrate that primary IPEPs can reduce the short-term risk of the knee, ankle, and shoulder injuries by up to 50% under ideal controlled conditions [4–6]. Ideally, these programs should then be widely adopted, sustained over the years, and ultimately achieve a maximum public health impact on handball players worldwide. Unfortunately, this is not the case in reality. Although compliance is often high during the intervention studies, such studies do not accurately reflect the real-world sport context in which the intervention is going to be implemented. Thus, IPEPs usually have limited impact on public health because they are not widely adopted or sustained into regular training routines [7]. An example from Norwegian handball illustrates that players and coaches stop using the program immediately after study end despite the gained knowledge about program effect [7]. In Denmark, only 62% of 679 youth handball players reported performing some of the IPEP exercises; however, only 3% implemented the full IPEP on a regular basis [34]. How to address this enormous research-to-practice/policy gap is

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a crucial important step in the real-world prevention of injuries in handball.

30.2 How to Enhance the Implementation Process

An IPEP will traditionally be developed based on results of injury surveillance and risk factor studies [8, 9]. In handball, risk factors have usually been described in a biomechanical or physiological sense. While this has led to efficacy when tested in randomized controlled trials, this does not guarantee a successful transfer of effective interventions across settings and contexts due to the complex interplay of social, political, organizational, and environmental factors that are not accounted for in the previous program developments [10]. To ensure significant population impact, sustained real-world prevention of sports injuries depends on a *behavior change* leading to adoption and sustainability of injury prevention exercises among players, coaches, clubs, and governing bodies in this complex context.

30.2.1 Understanding the Implementation Context

The process of implementing evidence-based practice in the real world is complex and challenging. Integrating behavioral and social science theories and models in studies on the implementation of promoting healthy behaviors, including injury prevention in sports [11, 12], is required to understand the implementation for the specific context [13]. For the sports field, a key challenge is to make sure that injury prevention exercises become a regular part of the practice of coaches and athletes [14]. To succeed in the implementation of IPEPs, it is important to acknowledge that there is no “one size fits all” for either preventive training or implementation strategies. Therefore, it is important to work through a structured process involving relevant stakeholders in identifying the “right” program and the “right” implementation strategies for each context.

30.2.2 Engage All Stakeholders

Emery and co-workers have developed a theoretical ecological model defining relevant stakeholders and a responsibility hierarchy in preventing injuries in youth sport [12]. The lowest level of responsibility is assigned to the child (player) who is the health beneficiary of the IPEP. For the majority of handball players, coaches are the program deliverers as they determine the types of activities performed by team members. Players’ adoption of injury prevention behaviors and how the exercises are executed is, therefore, strongly influenced by the coaches’ knowledge of and attitudes toward prevention practices [15]. The coaches’ knowledge and attitudes are often influenced by the clubs’ and governing bodies’ understanding about injury prevention and whether or not this is something the organization prioritizes. In this capacity, these organizations perform a knowledge translation role to inform end users of the findings of injury prevention and safety promotion research by developing and disseminating resources, to hopefully positively influence the practice of safety in handball [16]. These organizations are thus assigned to have the greatest responsibility as the policy makers with the highest potential to influence the successful real-world implementation [12]. This model can also be applied to other target groups, such as adolescents and elite players. Medical staff and younger players’ caregivers are not included stakeholders in this model; however, these stakeholders also play an important role for implementing IPEPs.

An essential process in enhancing the ultimate impact of IPEPs is identifying the specific implementation components that influence the adoption, execution, and maintenance of IPEPs for all the abovementioned stakeholders in the specific context.

30.2.3 Barriers and Facilitators to Injury Prevention Uptake

To successfully achieve adoption and sustain use of injury prevention training, we first need to understand the barriers and facilitators of preventive actions within the particular sport context among the stakeholders at multiple levels [8, 11].

There is currently a paucity of research investigating these factors in handball. However, in the 2013 handball season, Møller and co-workers investigated the barriers and facilitators for injury prevention uptake among 480 Danish youth handball players and 31 coaches. This has provided some preliminary insight regarding the barriers and facilitators of an IPEP among the health beneficiaries and program deliverers. The players recognize their high risk of injury (80% agreement) and are willing to implement IPEPs if these reduce injury risk (84% agreement) and enhance performance (88% agreement). Coaches agreed that IPEPs are an important part of coach education (100%) and are the coach's responsibility to implement (87% agree). There is high agreement among players (73%) and coaches (87%) that coach motivation has a key influence on player motivation to participate in IPEPs. Qualitative interviews suggest that players and coaches felt that established IPEPs did not contain enough handball-specific exercises and do not enhance performance [34]. Similar implementation barriers are identified in youth soccer [17–19]. Furthermore, one study has highlighted insufficient fidelity to the IPEP itself [20]. In addition, our practical experiences are that many teams may have somewhat resilience to new initiatives.

These barriers certainly contest whether current IPEPs are feasible, practical, and applicable in reality. Firstly, players who start at the higher difficulty level as defined in the program or reach such a level have no further guidance or instruction on how to proceed. Naturally, this has an influence on motivation, and maintaining athletes motivated is essential for program implementation. Secondly, if the coaches do not know how to demonstrate and deliver the exercises properly, the IPEPs will not have the intended effect, likely influencing both the coaches and players' motivation to prioritize it in a tight time-schedule and in a result-driven environment.

Importantly, according to Møller et al., coaches also stated a lack of policy support from both the club and the Danish Handball Federation (Møller et al., personal communication). Based on the hierarchical model by Emery et al., key organizations involved in sports settings (such as the national and international handball federations) are identified as those with the highest potential to affect real-world prevention. Thus, support from such organizations is vital. One major barrier to knowledge translation by these organizations stems from the fact that research results are written *BY* researchers *TO* researchers. This leaves the real-world translation of the research findings into a deliverable and applicable language, to the governing bodies. Translation of research findings into practice is time-consuming and complex and requires an understanding of the process with regard to which research findings might influence future behaviors [16]. This is rarely something handball federations have the capacity or resources to do. Instead, IPEPs are at most located at the federation's web page leaving stakeholders at the next levels to find this information themselves.

Based on the identified barriers, it is imperative to increase the knowledge about the risk of injury and the need for injury prevention uptake for all stakeholders. This may be enhanced by embedding IPEPs in coaches' education programs and courses and by endorsement of IPEPs by sporting organizations and high-profile players.

To encompass the identified barriers for IPEPs implementation, development of new IPEPs should be considered. A likely effective approach to develop and implement injury prevention exercises in sport is to combine the evidence available from the scientific literature with the clinical experience of researchers and the context-specific knowledge of stakeholders and end users [21]. Alongside with program development, a clear practical delivery and implementation plan of the program should be scheduled engaging all stakeholders. An important part of the implementation plan is to ensure high levels of trainer competency and self-efficacy as they are essential and acknowledged drivers of implementation success [15]. Also, distinct support and policy from the organization is vital for the implementation plan to succeed. Program fidelity can be enhanced through adequate resourcing (manuals, apps, online resources, etc.), training, feedback and mentoring [14, 22].

Although clubs may have qualified people to deliver IPEP, they may need help with the implementation of the program into the training sessions. In Sweden, Ageberg and co-workers have an ongoing study involving youth male and female handball players (13–17 years)—"Implementing injury Prevention exercise ROutines in TEams and Clubs in youth Team handball (I-PROTECT)" [23]. The goal of this study is that the injury prevention exercises will become part of the athletes' regular training routines and the coaches' regular programs, thus helping to close the gap between evidence and practice. The I-PROTECT study takes an ecological participatory approach, incorporating the perspective of multiple stakeholders, where the research team integrates behavioral and social science theories and models with sports medicine and public health perspectives. The series of studies are conducted in a real-world sport setting in collaboration with two handball clubs and the regional and national handball associations. In the first part of the I-PROTECT study, approx. 200 stakeholders (players, coaches, caregivers, and club, district, and national handball administrators) participated in a brainstorming in response to the question "To make injury prevention training a part of our regular handball training routines I need…." This generated approximately 90 unique "facilitator" statements. A smaller number of stakeholders then sorted the statements yielding clusters. These clusters included statements on, e.g., understanding, education, knowledge, exercises, routines, and club policy. The stakeholders also rated all statements according to importance and feasibility. The preliminary results suggest that developing an evidence-based context-specific IPEP and an associated context-specific implementation plan in partnership with all stakeholders should be a high priority to ensure successful IPEP implementation in youth team handball [23].

In addition, players, coaches, and administrators need support to maintain IPEP implementation over multiple seasons. This can be enhanced by establishing systems, policies, and procedures within the teams and clubs. In addition, ongoing support in the form of evaluation, funding, and mentoring are needed [14, 22].

In summary, to maximize preventive impact, IPEP implementation needs to target multiple levels of the handball sport system, including players (the health beneficiaries), coaches, and other staff (the IPEP deliverers) and administrators (the policy makers) [22]. Table 30.1 lists some of the known barriers for injury prevention uptake and provides examples of how to address them based on existing knowledge in combination with our practical experience.

Table 30.1 Barriers to injury prevention uptake and suggestions how to turn barriers into motivators by involving stakeholders relevant to the particular context in handball

Stakeholders	Barriers	Suggestions for how to turn barriers into motivators
Players	• Lack of knowledge about injury risk and injury prevention benefits • Lack of motivation • Too few ball exercises in IPEP • New coaches = New training routines	• Increase knowledge by available app's like Skadefri and Getset. Have national team players talking about IPEPs in videos that can be shared though social media • Have a role model on the team who advocates injury prevention • Include handball relevant exercises with ball and the potential to include new exercises and progression of exercises in the IPEPs • Define a general injury prevention policy in the club that new coaches will have to follow
Caregivers	• Lack of knowledge about injury risk and injury prevention benefits	• Have national team players talking about IPEPs in videos that can be shared though social media • Inform caregivers about the club's policy regarding injury prevention, provide them with easily read information by e.g. skadefri.no or fittoplay.org. and involve them in their child's attitudes and actions towards injuries and injury prevention

Stakeholders	Barriers	Suggestions for how to turn barriers into motivators
Coaches	• Lack of knowledge about injury risk and injury prevention benefits • Do not know how to execute the exercises properly • Lack of time • Players not motivated • Too few ball exercises and progression steps in IPEP • Hard to find information	• Make injury prevention mandatory in all coach educations + increase knowledge by available app's like Skadefri, Getset and others. Have national team players talking about IPEPs in videos that can be shared though social media • Include clear guidance on how to execute the exercises, and organize the IPEPs in the dissemination material. Enhance program fidelity through app's or other online resources, training, feedback and mentoring • Integrate exercises from IPEPs as a part of normal training and strength training routines[a] • Coach motivation improve player motivation • Define a player role model on the team who advocate for injury prevention • Include handball relevant exercises with ball and the potential to include new exercises and progression of exercises in the IPEPs • Encourage handball federations and other governing bodies to define a strategy on how they translate and disseminate up to date injury prevention knowledge to end-users
Medical staff	• Many youth clubs do not have medical staff assigned • Coaches take participation decision against the advice from medical personnel	• If applicable, prioritize medical personnel as a part of the club policy, and give them the responsibility to make decision about return to play after an injury • If it is not applicable to employ medical personnel, involve them in within-club coach education regarding injury risk and IPEPs
Clubs	• Lack of knowledge about injury risk and injury prevention benefits • Lack of injury prevention policy	• Encourage handball federations and other governing bodies to define strategy on how they translate and disseminate up to date injury prevention knowledge to end-users
Governing bodies	• Lack of knowledge about injury risk and injury prevention benefits • Do not have the knowledge and resources to knowledge translate, develop and disseminate research results to end-users	• Establish collaboration with researchers to inform them with up-to-date injury prevention knowledge • Discuss how knowledge of injury prevention initiatives best can be knowledge translated and disseminated to end-users with advertising/or communication personnel • Define a clear injury prevention policy

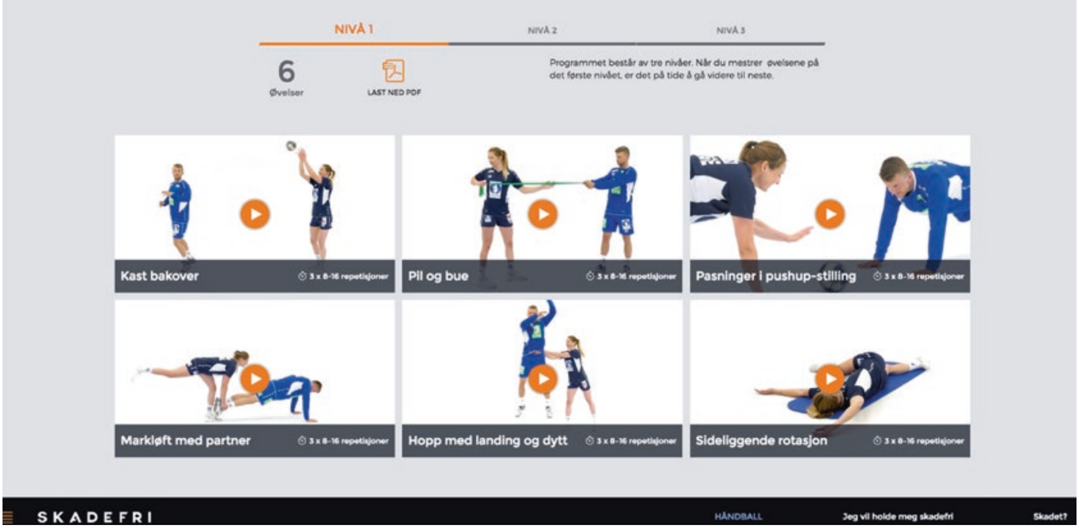
[a]Practical examples provided in text

30.3 Practical Examples of How Injury Prevention Can Be Organized in a Real-World Context

Adherence to injury prevention training highly depends on a very strict supervision in the initial period and also a certain development/variation of the exercises throughout the season.

As described, many teams may have resilience to new initiatives, which could be addressed in several ways. An important issue bigamy lies in the large differences in terms of facilities and time availability between the top elite level, with 6–8 weekly training sessions and unlimited access to court-time as well as fitness facilities, and youth teams with 3–4 weekly training sessions with limited court-time. In youth teams, aerobic training as well as strength training must often be carried out immediately before or after the handball training because time on the court may be as low as 3 × 60–90 min, and this may limit the coach's motivation to spend valuable court-time for injury prevention.

Currently, no studies have investigated if the effect of an IPEP is influenced by the integration of the exercises into different parts of training. It may be fair to assume that the important factor



Programmet består av tre nivåer. Når du mestrer øvelsene på det første nivået, er det på tide å gå videre til neste.

Fig. 30.1 Skadefri web-page and mobile application. Practical examples of handball specific injury prevention exercises can be found on the web-page and mobile application Skadefri. The exercises are divivied into three difficulty-levels (www.skadefri.no)

is not the order or timing of the exercises in the weekly training sessions but instead the total amount of repetitions per week that may produce the desired effect.

In addition, moving away from promoting one particular program, and introducing a variety of exercises based on principles instead, may enhance the real-world implementation. This would provide the coaches with the possibility to vary between the exercises and creativity to a large extent and, thus, potentially increase motivation in both players and coaches.

For the prevention of knee injuries, focus should be on correcting dynamic/biomechanical malalignment ("by keeping the knee aligned with the hip and foot") during the initial loading phase of landing and side cutting while also enabling the neuromuscular activation of the hamstrings and hip external rotators. Hip external rotator strength seems important for controlling the hip joint during the initial load absorption phase of the landing. In addition, lack of hip external rotator strength has also been associated with increased injury risk [24, 25]. Hamstring strength and quadriceps strength may be important for stabilizing the knee joint and enabling adequate load absorption through sufficient knee flexion during landing. However, no direct association of hamstring strength to injury risk has been shown in handball [26].

For shoulder injuries, an IPEP should in particular focus on external rotator strength, as well as scapular and truncus muscle strength/control. The above considerations are the practical background for the following suggestions for organizing preventive training in handball. Practical examples for specific exercises and an example of how a warm-up session may be organized can be found on the following home page: http://www.skadefri.no/ (English version www.fittoplay.org) and www.dgi.dk/haandbold/oevelser?emner=59. The exercises are also available on the following mobile applications for both android and iPhones: Skadefri, GetSet, and DGI Trænerguiden (Fig. 30.1). Skadefri web-page and mobile application.

30.4 Practical Examples of How Injury Prevention Can Be Organized During Warm-Up

When organizing injury prevention exercises, it may be useful to divide the exercises into three main categories:

(1) strength and mobility exercises; (2) running, coordination, and jumping exercises; and (3) throwing exercises. This may facilitate an easier integration of the exercises into different parts of the training session and as such likely have a longer-lasting adherence.

1. Strength and mobility exercises (6–8 minutes)
   The focus for these exercises should be:
   - Activation/strengthening of the posterior shoulder elements—particularly the external shoulder rotators
   - Hamstrings activation/strengthening
   - Core muscles activation/strengthening
   - Spine mobility
   - Choose between four and six exercises (variation).
2. Run, coordination, and jump exercises (6–8 minutes)
   The basic principles for these exercises should be:
   - Correct hip, toe, and knee alignment
   - Controlled and soft landings
   - A preferred two-leg landing strategy
   - Throwing with partner
   - Mobility in spine

Supervision is important for feedback on correct technique in the exercises. After thorough introduction, the feedback may be delivered using a teammate acting as a training partner or "spotter." This could also facilitate progression in difficulty level by adding external perturbation from the training partner during jump and landing exercises, as well as other exercise progressions which may also be added (e.g., kangaroo-like jumping exercises by having elastic rubber bands around the knees for extra strength-demanding stimuli to the hip external rotators).

Also, as throwing exercises are an integral part of the warm-up, it is important to include exercises focusing on shoulder external rotation, spine mobility, and working on all aspects of the kinetic chain.

3. Throwing with partner (6–8 minutes)
   - "Drop and catch" throwing
   - Throwing while standing on one leg
   - Gradually increased throwing speed

30.5 Practical Examples of How Injury Prevention Exercises Can Be Organized Outside the Handball Court

Weight training has traditionally been focusing on performance enhancement and as such been focusing on increasing strength and power of the antigravity muscles and the front side of the thorax for increasing throwing velocity. If the antagonist muscles have been included in these traditional programs, it has often been as exercises with much lower load than the exercises of the front side agonist muscles. This may lead to an imbalance in strength development from agonist to antagonist (typically front-to-back plane), which may increase the risk of injury. Since most elite handball players perform extra strength or weight training in addition to the training on the handball court, it is an opportunity to include IPEP exercises aiming at strength improvement of specific muscle groups in this program. Out of a weight training program comprising 8–10 exercises, 4–5 exercises could be included as injury prevention exercises.

An IPEP for knee injuries should always include strength exercises for the hamstrings, such as the kettlebell swing and the Nordic hamstring curl. These exercises are difficult to perform for many people, making them less appealing and applicable as warm-up exercises. It may, therefore, be easier to integrate these exercises in the weekly strength training sessions outside the handball court.

The kettlebell swing exercise is easy and safe to implement in the strength training program [27].

Kettlebell Swing

Player stands in front of kettlebell with his feet parallel a shoulder width apart.
To achieve the optimal hamstring muscle recruitment during the kettlebell swing exercise it is important to emphasize that the player has to forcefully swing the kettlebell back between the legs - by flexing the hip while keeping the knees nearly straight.

From above position, the player quickly reverse the direction with an explosive extension of the hips swinging the kettlebell out to chest level where the hips and knees are extended and the subject is standing upright.

However, in order to implement the kettlebell swing exercise, handball teams need to have access to kettlebells, which may be a limitation. Alternatively, the Romanian Deadlift exercise can yield the same hamstring muscle activation. For novices, both exercises need to be carefully introduced and supervised by a skilled person [27].

Romanian Deadlift

The player is standing close to the barbell with the feet parallel a shoulder width apart. The player grasps the bar by flexing the hips and keeping the upper body straight. Knees are slightly flexed.

The barbell is lifted by extending the hips and knees until standing in upright position.

The Nordic hamstring exercise is an excellent exercise to activate the hamstring muscles at high levels and is also included in the IPEP described by Olsen and colleagues [5]. This exercise can be performed by all players, regardless of age and playing level. It is very easy to implement as it can be performed both indoors and outdoors. In addition to being a vital exercise in knee injury prevention, a study in soccer has demonstrated that including this exercise in the weekly training plan reduces the incidence rate of hamstring injuries [28].

Nordic Hamstring

The player is kneeling on a balance mat (or other soft cushion) while the partner holds the ankles.

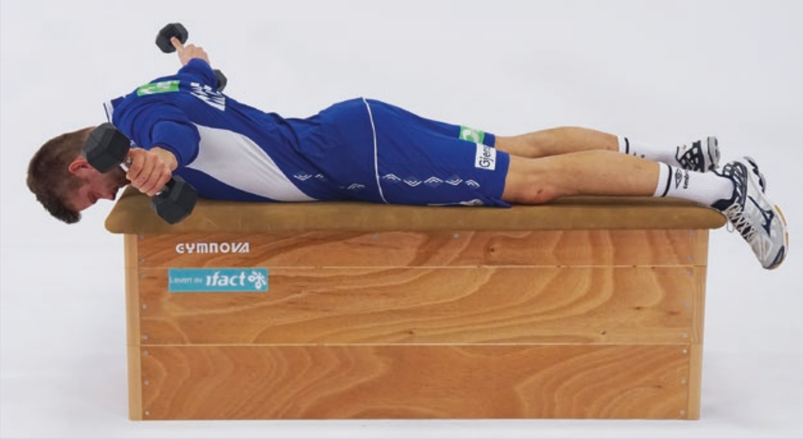
The player leans the upper body slowly forward, keeping the hips extended, and using the hamstrings to resist falling forward for as long as possible [27].

Nordic hamstring.

For an injury prevention strategy targeting shoulder injuries, specific external rotator strengthening exercises and scapula controlling muscles should be included. The following exercises are aimed at strengthening these muscles and target the presumed optimal muscle balance for enhanced scapular control [29–31].

Horizontal Abduction with External Rotation

The player is lying in the prone position with the shoulders resting in 90 degrees' forward flexion.



Then the player performs horizontal abduction to horizontal position with additional external rotation of shoulder (thumbs pointing up-wards) [30].

Shoulder Press

The player stands in front of a small box holding a dumbbell in the throwing arm.

He then takes a step up with the contralateral foot while he places the dumbbell in front of the shoulder.

He continues his step up and while he takes the ipsilateral knee and hip into flexion like in a jump shoot and pushes the dumbbell straight up [29].

The exercise can also be performed in a sitting position [29].

The player holds a dumbbell in his throwing arm and places the arm in 90° abduction and in maximal internal rotation.

He then externally rotates the shoulder while holding the abduction movement [31].

In addition, all shoulder exercises described by Andersson and colleagues [32] available at http://www.skadefri.no/ can be implemented during the training outside the handball court.

30.6 Practical Tips on How to Increase Knowledge Translation of Injury Prevention Initiatives

30.6.1 Lessons from the Norwegian ACL Injury Prevention Study

As previously described, Myklebust and colleagues initiated the first ACL injury prevention study in handball, looking at the efficacy of IPEP intervention. The 1998–1999 season served as the baseline for the Norwegian ACL injury prevention study; during the 1999–2000 season, an injury prevention program was introduced in the top three divisions in female handball in Norway [7]. The intervention consisted of a neuromuscular training program with exercises on a wobble board, a balance mat, and handball-specific exercises. In the first season (1999–2000), the intervention was based on coaches delivering the program after being instructed by the investigators. However, as compliance was low, physical therapists were engaged to take charge of program delivery during the second intervention season (2000–2001). As previously mentioned/presented, this intervention demonstrated a significant reduction in the numbers of ACL injuries [4].

After the conclusion of the ACL prevention study in Norway, the number of ACL injuries in the three top level divisions was surveyed for 10 years. An increase in ACL injuries was already evident in the first year after the intervention had been stopped. From player-interviews, the authors realized that the promising findings from the ACL injury prevention study did not result in the program being implemented as a regular part of training by coaches or players. As previously mentioned, the teams and players stopped doing the prevention program after the research study was concluded at the end of the 2000–2001 season.

Several measures were made in the following years to change this negative trend. In order to increase knowledge and improve compliance and approach among coaches and managers, a series of regional coach seminars were organized free of charge in 2005. Seminars were held in Norway's five largest cities and were attended by handball coaches, managers, and players. In addition, the prevention study among youth handball players by Olsen et al. [5] was published and received extensive media attention via newspapers, television, and an article in the Norwegian Handball Magazine which was received by every member of the Norwegian Handball Federation. After this information campaign, there was a substantial reduction in the ACL injury rate. These low numbers have remained low in the subsequent seasons.

Probably the most important factor to the ACL injury reduction over the years has been the constant involvement of the Norwegian Handball Federation (NHF). This is a strong example to the previously described importance of the governing bodies/policy driving key stakeholder's involvement to successful real-world injury prevention. Just as handball is a team sport and a good team effort is necessary for success in the sport, injury prevention cannot be successful without a team effort. As part of such a team effort, the Oslo Sports Trauma and Research Center (OSTRC) has continuously supported the federation with the knowledge translation of new established research to players and coaches. This has established the necessary knowledge and understanding of the importance and benefits of injury prevention within the federation, which is disseminated through the circles of other stakeholders. As an example, a session with updated injury prevention knowledge is now regularly integrated in the yearly top handball coach seminar in Norway. To further increase the knowledge and appeal to coaches and other stakeholders, the NHF and OSTRC have created a series of videos with national team players talking about the importance of injury prevention and providing practical examples of their favorite exercises, which are broadcasted during national tournaments/during matches. The aim is to inspire young players and parents. As a result, today, most young Norwegian players are familiarized with "knee over toe" landing and safe cutting movements.

Another important contribution has been the development of an injury prevention web page (http://www.skadefri.no/) and complementing mobile application: Skadefri, launched by the OSTRC in May 2008, which in 2017 has also been launched in English at: fittoplay.org. Currently, Skadefri is served by OSTRC in close collaboration with the Norwegian Olympic Sports Centre (Olympiatoppen) and other Norwegian associations. Skadefri is designed to provide information on the most common injuries in all Olympic sports and how to prevent them and in a format targeting physiotherapists, doctors, coaches, athletes, recreational exercisers, students, and anyone interested. It is free and without any commercial interest. The IPEPs presented at Skadefri are based on research, if applicable. To enhance the knowledge translation of injury prevention exercises, federations, coaches, and players are encouraged to provide feedback in the development of the IPEP. All exercises from Skadefri have been translated into English, German, French, Spanish and Chinese and are avaliable in the GETSET app.

In summary, the experience from the Norwegian ACL studies indicate that the ACL injury rate can be kept low through nationwide preventive initiatives and by focusing on the handball federation and coaches as key stakeholders. It still unclear which initiatives are the most effective, as well as the ideal exercise prescription.

30.7 Perspectives

This chapter has provided practical examples and guidelines on how IPEPs may be better implemented in a "real-world" context based on existing knowledge in combination with our practical experience. Further research within injury prevention is needed to support these recommendations. In addition, the development of primary preventive recommendations based on training load management is paramount to better influence the outcomes. Recently, Drew and colleagues presented directions of training-related injury prevention recommendations [33]. In their example, the risk of injury could be ameliorated by (1) more training in the daily training environment prior to attending a period with many matches or a training camp, (2) less training and matches at the camp, or (3) a combination of both such that prescription is individualized [1]. However, to date, no RCTs in handball or any other sports have investigated the effectiveness of controlled adjustment of load on the development of any injuries. The major challenge in such studies is compliance to the suggested load management strategies. Therefore, efforts should be made to involve all stakeholders in any future recommendations regarding load management in handball to ensure that the suggestions are effective and applicable in a real-world context. How to address these issues is a crucial important next step in the prevention of injuries in handball.

Practical key points and applications on how to enhance the implementation of IPEPs into real world:

- Engage key individuals of stakeholders from multiple levels when designing IPEPs. Understanding stakeholders' implementation barriers may help to find appropriate solutions for injury prevention uptake.
- Increase knowledge about the benefits of IPEPs to all stakeholders by available web pages and mobile applications like Skadefri or GetSet. These platforms can also be used to enhance program fidelity.
- Make injury prevention mandatory in coach education.
- Clubs and governing bodies should have a clear injury prevention policy.
- IPEPs should be integrated as a part of the normal training and strength training routines.

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Rehabilitation of Upper Extremity Injuries in the Handball Player

31

Ann Cools, Rod Whiteley,
and Piotr Krzysztof Kaczmarek

31.1 Introduction

Handball is one of the Olympic sports with the highest risk of injury, according to results from the IOC injury and illness surveillance system [1]. The game is characterized by a high playing tempo, rapid changes of movement, jumps with hard landings, frequent contact and collisions between players, as well as repetitive knee and shoulder joint stress [2, 3]. Although rules exist to make the sport safe and fair, players are vulnerable for both acute and overuse injuries [4].

The risk of injury in handball is significantly higher during match play than in training, probably explained by higher intensity, more aggressive behavior, and more frequent contact between players [5, 6]. However, it is still unsure whether the risk of injury changes throughout the time course of the match or if the risk of injury or pattern differs between player positions. Epidemiological studies have reported that, in general, the knee and ankle are the most common locations for acute injuries, while overuse problems primarily affect the knee, lower leg, and shoulder [7, 8]. Epidemiological data in handball are mainly based on injuries among players on the national division level, as there are limited data on elite international players [4].

31.2 General Principles of Rehabilitation of the Upper Limb in the Handball Player

Upper limb injuries in handball may be **traumatic**, with an acute onset, or **overuse**-based with a gradual onset and progression. While handball is a throwing sport, it is also a collision sport, and both traumatic and overuse injuries have a high prevalence. As pointed out elsewhere in this text (Chap. 17), in contrast to other throwing sports, the primary cause of elbow injury is repetitive traumatic impact. Conversely both traumatic and overuse injuries often occur in the shoulder, with more time-loss from play for overuse injuries, making the latter a larger category of injury to understand and treat. The assessment and management of these injuries demands a different approach. The different patterns of injury need to be considered differently for the treating practitioner. In acute injuries,

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such as AC joint injury, shoulder or elbow dislocation's early protection of the site of the injury is important, and the therapist should follow the natural tissue healing process through the inflammation, proliferation, and remodeling phase. In chronic throwing-related pain however, the assessment and treatment should encompass the possible overload mechanisms, functional impairments, and intrinsic risk factors, including the global kinetic chain.

Shoulder or elbow pain in the handball player is **multifactorial** and may have several underlying causing factors, structural and functional. The treatment approach must be based on the results of the clinical examination, including thorough analysis of possible functional impairments [9, 10], and any diagnostic imaging and may comprise several of the treatment strategies described below. In case several factors are identified within the **kinetic chain**, it is imperative to start the treatment dealing with correcting the most proximal parts in the kinetic chain.

In **acute injuries**, four **phases** can be recognized in the rehabilitation of the overhead athlete [11]: (1) acute phase, (2) intermediate phase, (3) advanced strengthening phase, and (4) return-to-play phase. In the acute phase, the goals are to diminish pain and inflammation, normalize motion, delay muscle atrophy, and restore dynamic stability. Strengthening exercises focus on rotator cuff and scapular retractors. Functional loading is limited until full range of motion is restored. During the intermediate phase, strengthening exercises progress into isotonic training of the shoulder girdle and the core, and flexibility is controlled by intensive stretching exercises, in particular of the posterior shoulder structures. The advanced strengthening phase consists of more aggressive strength training, including power and endurance enhancement. A plyometric program, endurance drills, and controlled throwing are initiated. In the return-to-play phase, the athlete progressively increases the throwing program, continues flexibility drills, and prepares return to competitive throwing and collisions.

Overuse injuries have a gradual onset and are often recurrent. Treatment progression is mainly based on **tissue irritability** [12]. In case of high irritability (constant or night pain, pain >7/10, high disability), a relatively brief period of de-loading is likely indicated. When the injury is characterized by low irritability (absence of constant of night pain, pain <3/10, low disability), moderate to high physical stress should be applied, including restoration of high-demand functional activity.

Many different **exercise modalities** may be applied during the rehabilitation. **Closed chain** as well as **open chain exercises** may be prescribed. In closed chain exercises, the final link of the chain, in case of the upper limb, the hand, is supported on a surface, which is fixed or moveable. As a result of the compressive forces in the shoulder, the patient feels safer to preserve the local glenohumeral stability. In addition, closed chain exercises stimulate normal proprioceptive pathways, enhance local co-contraction in the stabilizing muscles, and minimize translations in the midway of motion. However, in view of the functional demands of handball which require functional stability during open chain overhead throwing, the limitations of the closed chain exercises are that they do not prepare the athlete to full return to sport and do not load the tissues around the shoulder in the most functional way, thus jeopardizing tissue-specific adaptation to training. In open chain exercises, the hand is free to move in space (with or without an additional resistance), and shear and translational forces are caused in the glenohumeral joint, increasing the challenge for shoulder stability. It is imperative these exercises are implemented in the rehabilitation program of the handball player on the condition the athlete feels safe performing the exercise (for instance, in case of glenohumeral instability).

Exercise prescription may also be based upon **muscle recruitment patterns during exercises** in order to promote activity of the assumed weak muscles with simultaneous inhibition of the assumed overactive muscles. Many commonly used rehabilitation exercises have been analyzed with electromyography to determine the predominant muscle activity patterns, thus assisting the therapist in the exercise choice. Depending upon the specific muscle performance deficits, progressive exercise programs are described for the

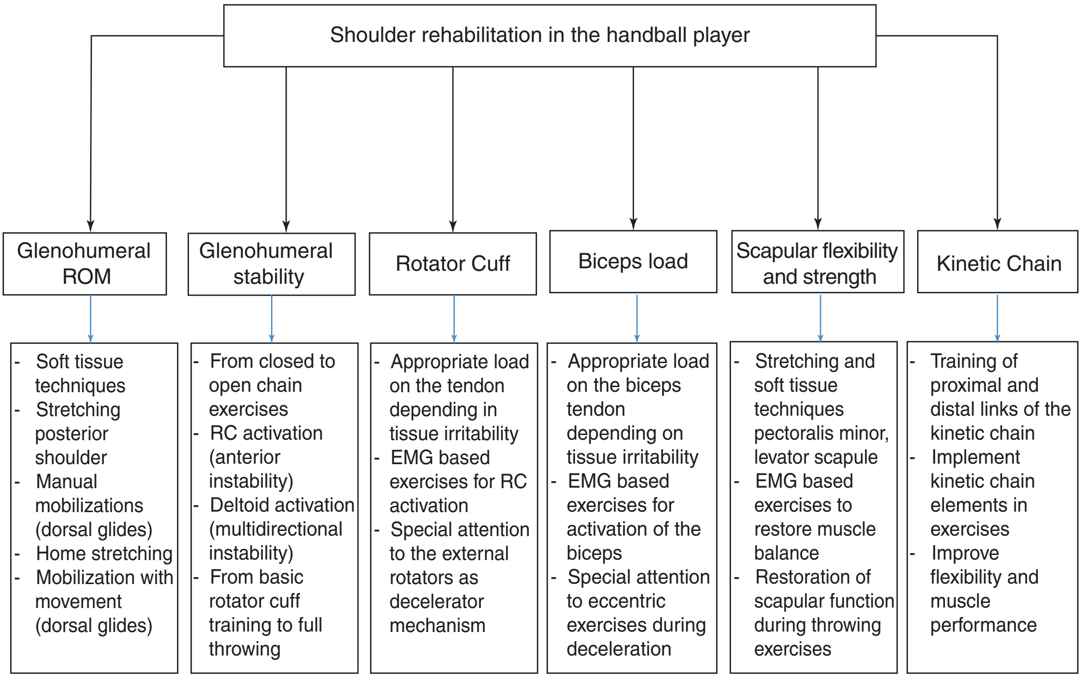


Fig. 31.1 Shoulder rehabilitation in the handball player: overview

scapular muscles [13–16], the biceps complex [17, 18], and the rotator cuff [19].

The aim of this chapter is to focus on region-specific rehabilitation, to describe shoulder (Fig. 31.1) and elbow rehabilitation strategies (Fig. 31.19), however also to highlight the importance of the functional kinetic chain in upper limb rehabilitation, as well as discuss the return-to-play procedure of the handball player following an upper limb injury.

31.3 Rehabilitation of the Shoulder

31.3.1 Restoration of Normal Glenohumeral Range of Motion

Posterior shoulder stiffness is the most common adaptation seen at the dominant side of overhead athletes of multiple sports disciplines [20]. In elite handball players, it was found that for every 5 degrees increase in total rotational motion, the odds of shoulder injury were reduced by 23% [21]. Given the impact of posterior shoulder tightness on shoulder kinematics, increasing posterior shoulder flexibility is suggested when these deficits exceed the limits associated with increased injury risk. Both the cross body stretch (Fig. 31.2a) and the sleeper stretch (Fig. 31.2b) can be recommended to decrease posterior shoulder tightness. It was shown that a 6-week daily sleeper stretch program (3 reps of 30 s) is able to significantly increase the acromiohumeral distance in the dominant shoulder of healthy overhead athletes with GIRD [22]. Additional joint mobilization performed by a physiotherapist has a small but nonsignificant advantage over a home stretching program alone [23]. No difference in mobility gain was seen after angular (sleeper stretch and horizontal adduction stretch) and non-angular (dorsal and caudal humeral head glides, Fig. 31.3a, b) joint mobilization by a physiotherapist [24]. Muscle energy techniques (hold-relax) during the sleeper stretch and the horizontal adduction stretch have proven useful to immediately increase internal rotation range of motion [25]. Two studies showed symptom relief after a stretching program in a population of

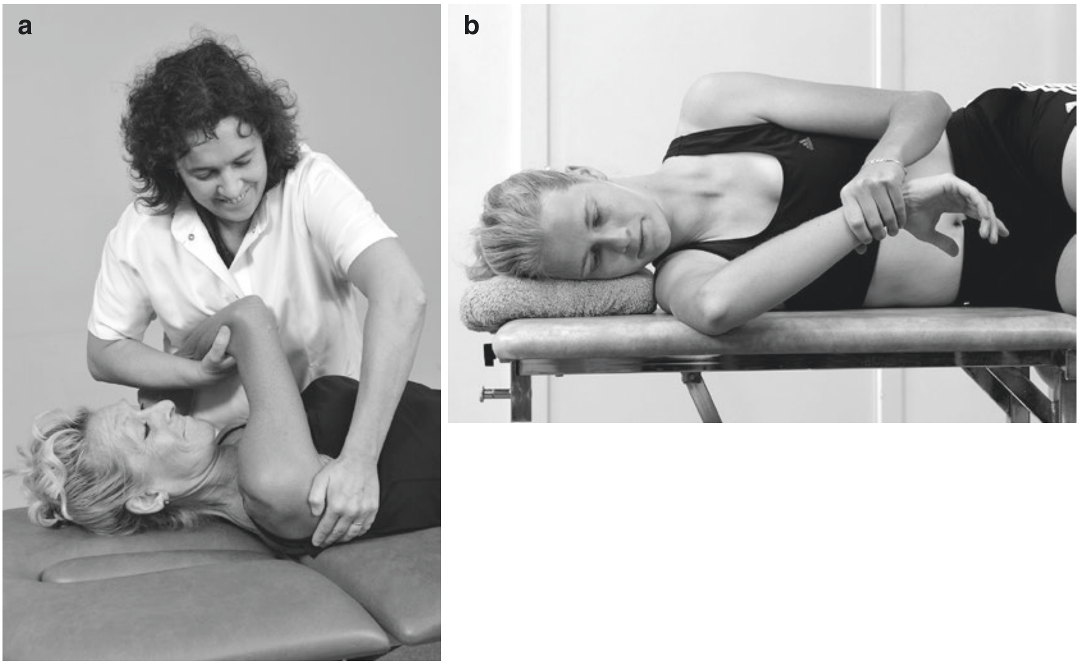


Fig. 31.2 (**a**) Cross body stretch and (**b**) sleeper stretch for stretching the posterior shoulder

overhead athletes with impingement-related shoulder pain [24, 26].

Since full ROM into all directions is necessary for optimal throwing performance, forward flexion and external rotation in abduction (ABER) also need to be addressed during rehabilitation. In view of the possible anterior translation of the humeral head in these positions, dorsal glides may be added during mobilization techniques (Fig. 31.4a, b).

31.3.2 Rehabilitation of Shoulder Instability

Based on the cause, direction, and typical clinical presentation of instability, patients may be divided into three groups: the TUBS (Traumatic Unidirectional instability with Bankart lesion, for which Surgery is often needed), AIOS (Acquired Instability due to Overstress Syndrome), and AMBRI (Atraumatic Multidirectional instability with Bilateral laxity, in which Rehabilitation is the first line of care, but in case of failure Inferior capsular shift surgery is performed). On the field these types may be combined, for instance, a player with general laxity (AMBRI) may develop overuse instability (AIOS), or a player with sport-specific minor instability (AIOS) experiences an acute trauma and dislocation (TUBS).

The rehabilitation guidelines for shoulder instability depend upon the kind of instability the patient exhibits and the degree or severity of the symptoms. In general, the three kinds of instabilities described need a different rehabilitation approach. Scapular rehabilitation and kinetic chain exercises are obligatory for all instability patients. However the focus during glenohumeral stabilization exercises may be given to the rotator cuff (in particular external rotators) in case of TUBS and AIOS, whereas control of the deltoid co-contraction is the key guideline in AMBRI rehabilitation. Additionally, contrary to TUBS and AIOS, closed chain exercises (with compression in the joint) are preferred in cases of AMBRI. Exercise progression in closed chain exercises may be given by increasing the load (body weight on the shoul-

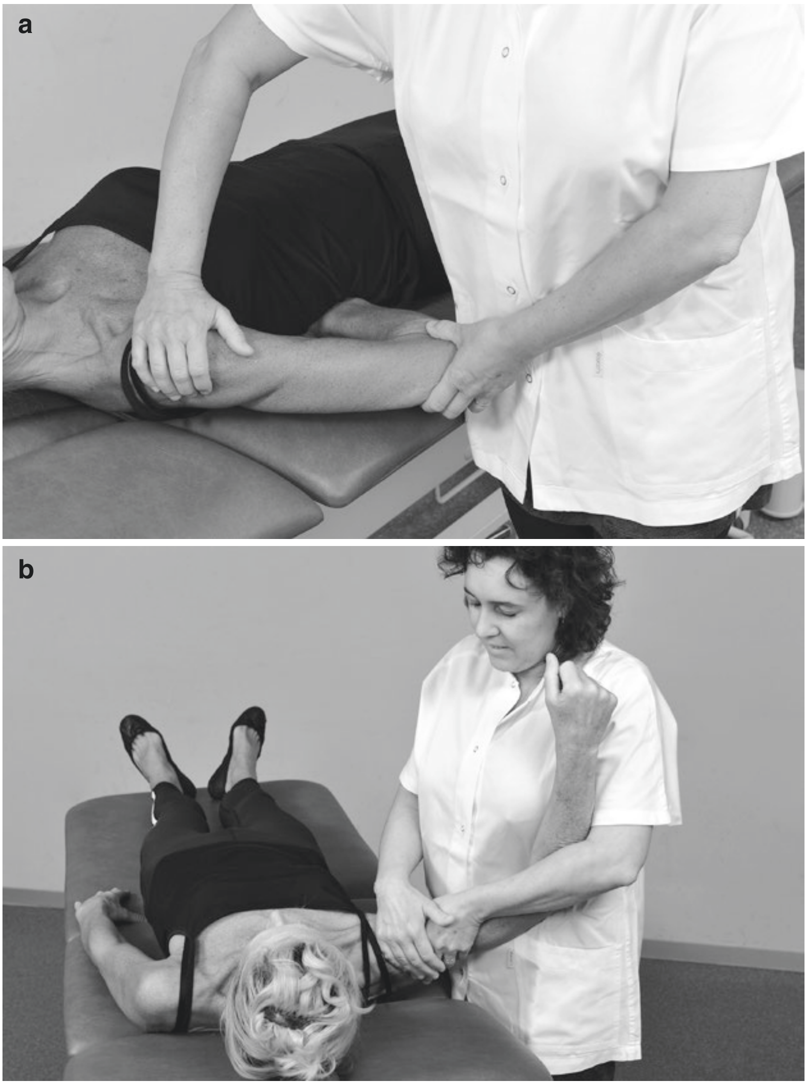


Fig. 31.3 Joint mobilization: (**a**) dorsal glides, (**b**) caudal glides

ders, Figs. 31.5a, b), transferring from static to dynamic shoulder exercises, and changing the plane of the movement between the sagittal and the frontal plane (Figs. 31.6a, b) [27]. Additionally, visual feedback, double tasks, and unstable surfaces may be implemented to further challenge functional shoulder stability. Open chain exercises should progress from basic rotator cuff training to full throwing capacity, focusing on internal as well as external rotational strength and explosive capacity. Special attention should be given to the eccentric strength of the external rotators, being the most important decelerator mechanism for the glenohumeral joint during throwing.

31.3.2.1 Neuromuscular Control and Strength Training of the Rotator Cuff

The etiology of rotator cuff pathology is multifactorial and has been attributed to both extrinsic and intrinsic mechanisms [28]. Extrinsic factors that encroach upon the subacromial space (subacromial impingement) or against the posterosuperior rim of the glenoid (internal impingement) include anatomical variants of

Fig. 31.4 Mobilization with movement: (**a**) forward flexion with dorsal glide, (**b**) external rotation with dorsal glide

the acromion, alterations in scapular or humeral kinematics, postural abnormalities, rotator cuff and scapular muscle performance deficits, and decreased extensibility of pectoralis minor or posterior shoulder. Intrinsic factors that contribute to rotator cuff tendon degradation with tensile/shear overload include alterations in biology, mechanical properties, morphology, and vascularity.

Treatment guidelines for rotator cuff pathology depend upon tissue irritability [12], the identified impairments, and patient's expectations [29]. In case of high irritability (for instance, reactive tendinopathy), load management with temporary reduction of frequency and intensity of load is advocated [30], and isometric contractions are advised. As a guide, we suggest submaximal contractions (starting with approximately 50% maxi-

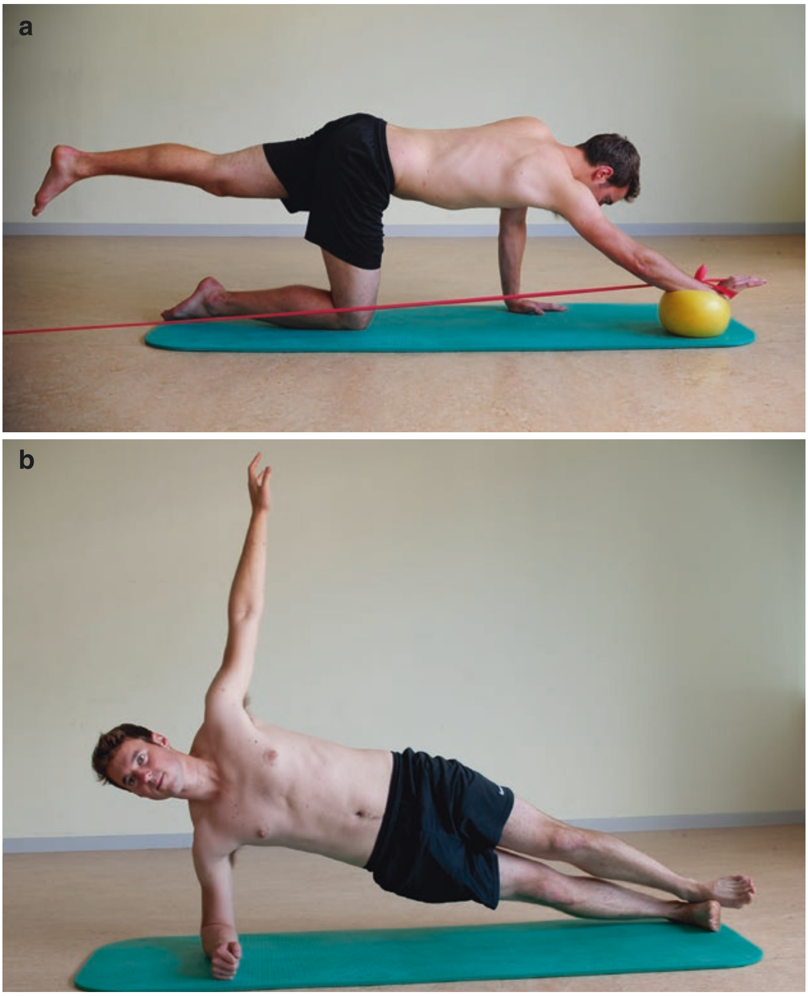


Fig. 31.5 (**a**) Moderate, and (**b**) high load closed chain exercises

mal strength and increase up to 70% if possible, according to patient response) in the direction of the pain and weakness. Contractions should be sustained for 30–45 s in sets of 3–5 repetitions, performed 3–5 times a day [31, 32]. In the presence of degenerative tendinopathy, or low irritability, moderate to high physical stress is allowed, specifically by using exercises with an eccentric component [30]. There is no consensus in the literature with respect to the modality (concentric versus eccentric), nor with respect to the pain allowed during the exercises [33]. Clinically we suggest pain is a pain-monitoring model [33, 34] considering up to 4–5/10 to be acceptable. Eccentric exercises may start in a slow manner, focusing on the eccentric phase by avoiding or minimizing the concentric phase (Fig. 31.7a–c), however, should progress in high-speed plyometric eccentric exercises in handball players, in view of the important role of the external rotators (supra- and infraspinatus) as a decelerator mechanism of the throwing arm [27] (Fig. 31.8).

31.3.2.2 Progressive Exercise Training for Overhead Athletes with SLAP Lesions and Biceps-Related Pathology

Biceps-related pathology may comprise injuries of the long head of the biceps (tendinitis, tendinosis, tenosynovitis, instability of the long head of the biceps) as well as SLAP lesions. Since the superior aspect of the glenoid labrum is continuous with the tendon of the long head of the biceps muscle [35], rehabilitation programs for SLAP

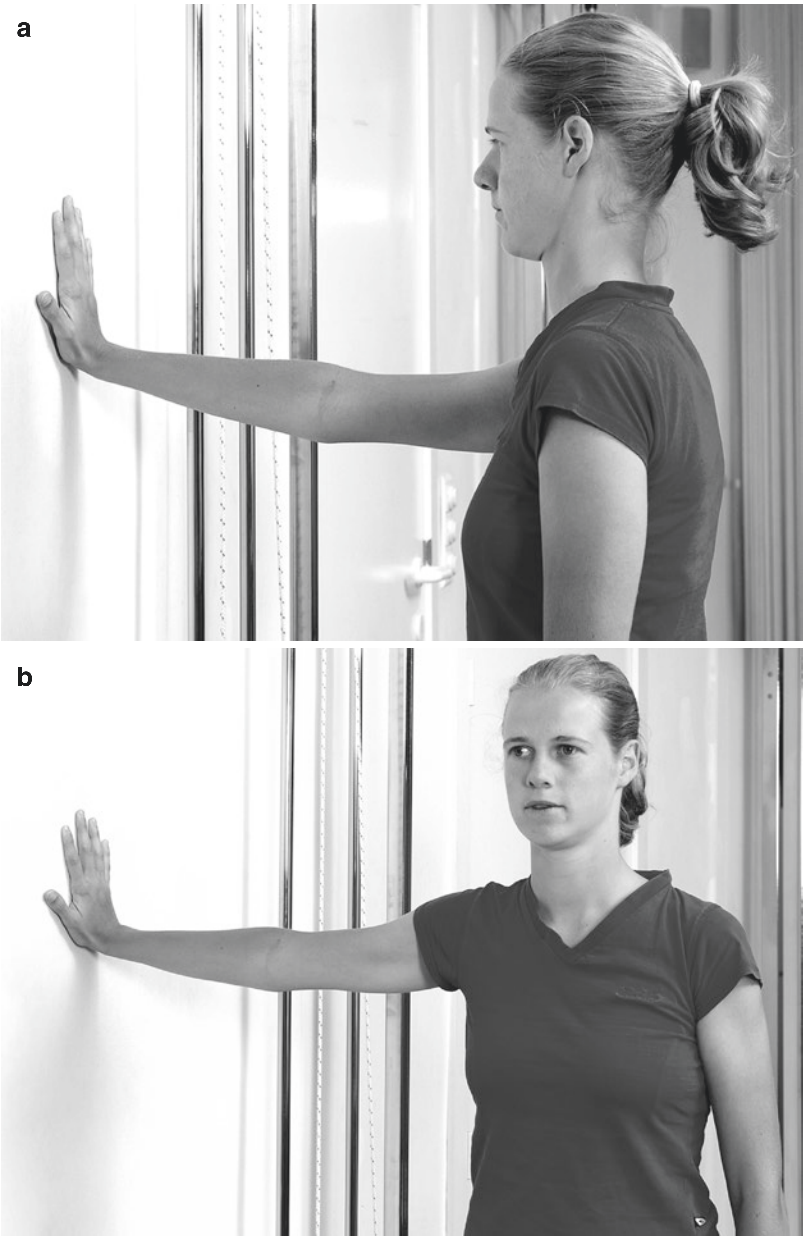


Fig. 31.6 Low load closed chain exercise in (**a**) the sagital plane, (**b**) the frontal plane

lesions should consider progressive load on the long head of the biceps throughout the exercise program, similar to biceps injuries.

In recent clinical guidelines, it is suggested that the vast majority of overhead athletes with nontraumatic SLAP lesions should be initially treated with nonoperative methods [36]. A recent randomized clinical trial showed that results of a SLAP repair or tenodesis were not superior to sham surgery in patients with an isolated SLAP tear [37]. In case of failure of rehabilitation, a traumatic onset, or severe labral injury (type III or IV SLAP lesion) surgery, may be needed, and here the discussion shifts to ideal operative technique which likely depends on the individual player's anatomy, pathology, and physical demands—a discussion of which is beyond the scope of this chapter.

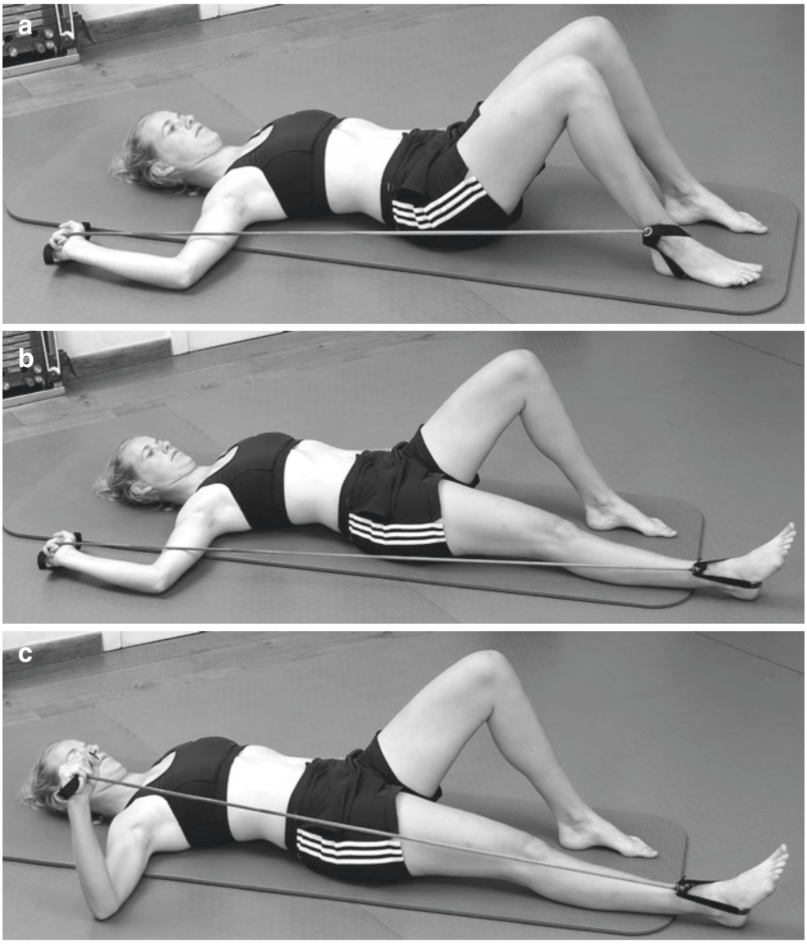


Fig. 31.7 Slow heave resistance eccentric exercise for the external rotators in 3 steps: (**a**) starting position, (**b**) increasing resistance by extending the leg, (**c**) eccentric load on the external rotators

Rehabilitation of biceps-related shoulder pain and SLAP lesions (conservative and postoperative) should follow the general guidelines containing a phased progression of rotator cuff exercises, scapular exercises, and stretching. However, tension on the long head of the biceps should be implemented carefully and increased gradually, with early protection of the site of the injury. In addition, in postoperative rehabilitation programs after SLAP repair, biceps activity needs to be controlled during the first 12 weeks following surgery, with no resisted biceps activity during the first 8 weeks to protect the healing of the biceps anchor, and no aggressive strengthening of the biceps for 12 weeks following surgery [38]. Importantly, if a biceps tenodesis was performed, the therapist will need to discuss with the surgeon the timelines for reinstating biceps loading as this will vary depending on the anchoring technique employed. In view of this treatment goal, a progressive program consisting of selected rotator cuff and scapular exercises with low to high load on the biceps (based on EMG analysis) was proposed, giving the clinician the opportunity to select the appropriate exercises based on the goals and the load on the biceps [17, 18]. In this continuum of exercises with an increasing level of EMG activity in the biceps, exercises targeting the trapezius resulted in less loads on the biceps (<20% MVC) compared with exercises for the serratus anterior. In addition, external rotation exercises showed low activity levels in the biceps, making them appropriate in early stages of rehabilitation, and exercises meant to target the biceps (such as resisted forward flexion in supination) (Fig. 31.9) showed moderate

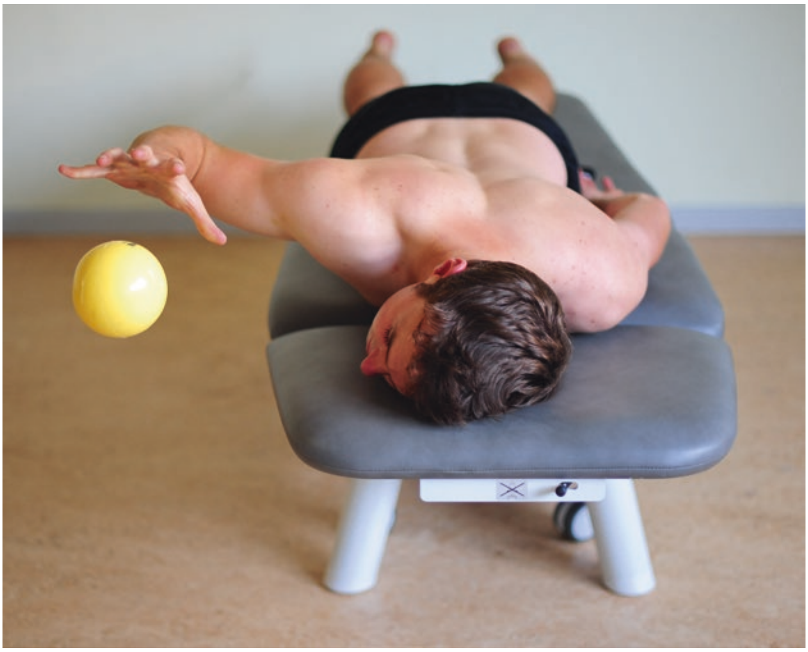


Fig. 31.8 High speed eccentric exercise for the external rotators

Fig. 31.9 Exercise with moderate load on the biceps: shoulder forward flexion in supination against resistance

(20–50% MVC) to high (> 50% MVC) activity in the biceps. Finally, plyometric exercises such as the reversed punch (Fig. 31.10) or forward flexion catching ball (Fig. 31.11) exhibited high biceps activation levels, making them appropriate in the return to sports stage of the rehabilitation.

Fact Box
During exercise prescription, the clinician may be guided by EMG studies examining relative muscle activity in the targeted muscles such as the rotator cuff, the biceps, or the scapular muscles.

31.3.3 Management of Flexibility Deficits in the Scapular Muscles

With respect to soft tissue inflexibility, tightness of the pectoralis minor has been established in relation to abnormal scapular position [39]. Other studies indicated excessive activity in the upper trapezius during elevation [40]. Increased scapular internal rotation, as well as increased anterior tilting, has also been demonstrated [41]. These alterations in scapular position are similar to the scapular deviations, established in patients with impinge-

Fig. 31.10 Exercise with high load on the biceps: reversed punch

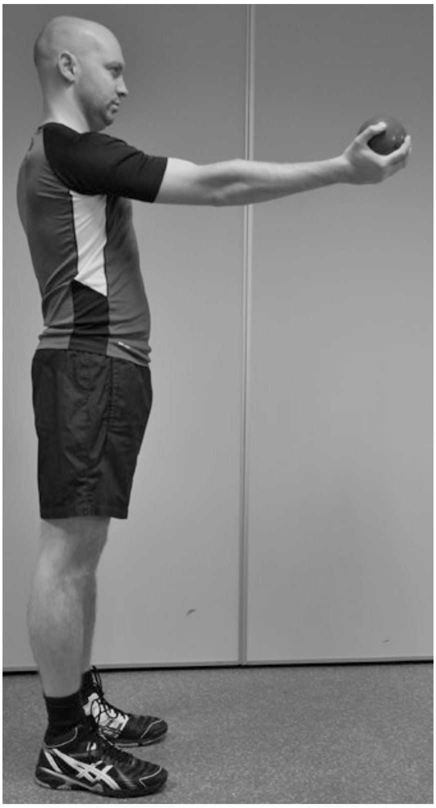


Fig. 31.11 Exercise with high load on the biceps: forward flexion catching ball

ment symptoms, and possibly put the shoulder at more risk for developing shoulder pain.

Several stretching techniques have been described to increase pectoralis minor length, however often in a position of abduction/external rotation which might be painful [42]. Therefore, the pectoralis minor might be stretched performing passive retraction and posterior tilting of the scapula with the shoulder in a neutral or small elevation position and slight external rotation (Fig. 31.12).

In addition to passive stretching techniques, exercises should be prescribed with minimal activity of the hyperactive muscles. Examples are elevation with external rotation (decreases pectoralis minor activity) (Fig. 31.13), wall slide (decreases levator scapulae activity) (Fig. 31.14), and side lying external rotation (decreases upper trapezius activity) [14–16] (Fig. 31.15).

31.3.4 Exercises for Scapular Motor Control, Muscle Balance, and Muscle Strength

Depending on the results of the clinical examination, the therapist may decide during scapular muscle training to focus more on motor control

Fig. 31.12 Manual stretching of the pectoralis minor

Fig. 31.13 Exercises with decreased activity in the pectoralis minor: elevation with external rotation

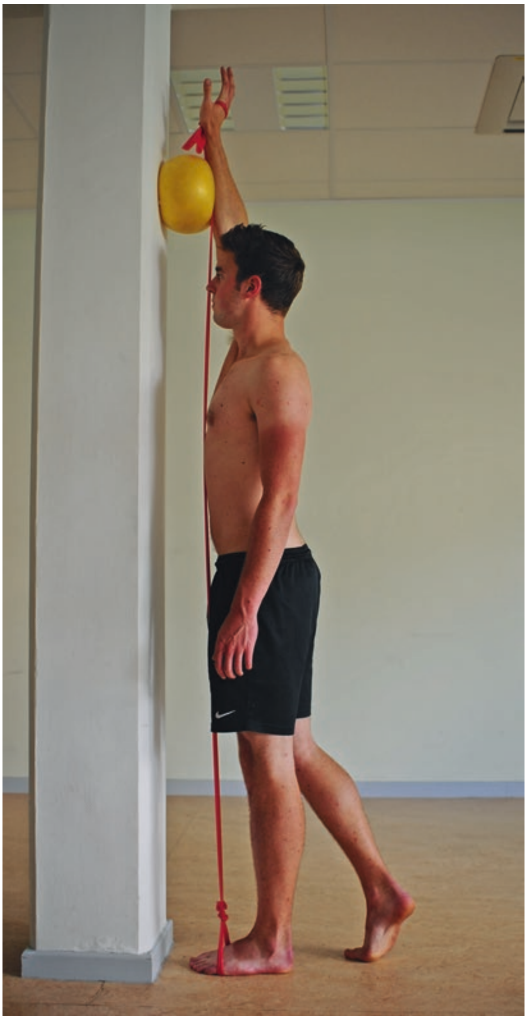


Fig. 31.14 Exercise with decreased activity in the levator scapulae: wall slide

Fig. 31.15 Exercise with decreased activity upper trapezius: side lying external rotation

Fig. 31.16 External rotation diagonal exercise

(appropriate co-activation of the scapular force couples) or muscle strength (in case of isolated strength deficit in one or more scapular muscles). In general, motor control exercises will be "low load" (<50% of MVC, 3 sets of 20–30 repetitions) functional movements (for instance, variations on elevation exercises or diagonal movements, Figs. 31.13, 31.14, and 31.16), since the aim is to automatize force couple activity around the scapula. In case of documented (based on manual muscle testing or handheld dynamometry) muscle strength deficits in a specific muscle group (for instance, decreased lower trapezius or serratus anterior strength), exercises are warranted to specifically target the weak muscle, often requiring isolated movements and a higher load (80% of MVC, 3 sets of ten reps). Examples are overhead retraction [15] (Figure 31.17) for the lower trapezius and elbow push-up [43] for the serratus anterior (Fig. 31.18).

31.4 Rehabilitation of the Elbow

The elbow joint in handball players is subject to great valgus stress and, as a result, is exposed to a wide variety of possible injuries. Most of these are overuse or overload injuries with chronic mild or moderate medial elbow pain. Repetitive valgus stress (throwing action) in field players results in overuse pathology of the dominant elbow. On the other hand, repetitive hyperextension stress of the elbow in goalkeepers (blocking the ball) provokes similar pathological changes bilaterally.

Note however that there is a cultural difference in handball of apparent underreporting injury compared to football [44] with 55% of

Fig. 31.17 Overhead retraction exercise

Fig. 31.18 Elbow push-up exercise

players continuing to participate despite injury, and differences have been documented in injury rates when comparing player- and coach-recorded injury epidemiology [6], so it's important for the clinician to establish a good relationship with their players to ensure minor injuries don't escalate and significant injuries are reported and managed appropriately.

Unfortunately for the practitioner, handball-related throwing injuries appear to have a different etiology to elbow injuries in other sports and therefore extrapolating from research in other areas such as baseball should be done with caution. It is suggested that a combination of the higher velocity and volume of throwing in baseball [45] is associated with the higher rate of chronic valgus extension overload, and this needs to be considered when extrapolating from the much richer vein of research in this area to handball. Throwing-related injuries do occur in handball, although less commonly, and they result in a similar final pathology.

Management of the traumatic elbow injury involves initial accurate identification of all the pathology. Typically the history will be clear; however long-standing repeated hyperextension injury can present in addition to throwing-related injury which may be a primary exacerbating cause [46, 47]. The player will likely present reporting symptoms which began after repeated blocking (goalkeepers) and then is subsequently provoked by blocking (less commonly through throwing and shooting). It appears that the mechanism of injury in goalkeepers is usually forced extension combined with valgus [48, 49]. Most commonly medial elbow pain is the primary presenting problem, although this is commonly associated with weakness, reduced range of motion, apprehension, numbness, swelling, but rarely frank instability [47]. The majority (60%) have pain which persists for more than an hour after activity, half for more than a day, and 15% report constant elbow pain [47].

Once throwing-related injury is suspected, it's critical to confirm the diagnosis as concomitant injury to the anterior band of the ulnar collateral ligament of the throwing arm and has management implications for the player who needs to be able to make high velocity throws. In handball, as opposed to baseball pitchers, the player with a torn ulnar collateral ligament in their throwing arm will almost always undergo a period of conservative care finishing with a graded return to throwing at pre-injury intensity and volume. Note that in contrast to other throwing-related elbow injury, the ulnar nerve appears typically to be spared damage [50], although it's always sensible to ask the player about sensory loss and quickly examine the hypothenar eminence for sensory and motor impairment as injury to the ulnar nerve will impact treatment options. Specifically care will need to be taken in resuming throwing (where tension on the ulnar nerve could exacerbate the injury) possibly impairing hand function (strength and proprioception), although rarely surgical intervention is required (medial transposition of the ulnar nerve).

The primary pathology in blocking-related hyperextension injury to the elbow appears to be: anterior capsule rupture, L-shaped tear of the flexor-pronator mass, elongation of the ulnar collateral ligament, then, less commonly, damage to the lateral collateral ligament and cartilaginous ulnar damage for an acute injury [51]. Handball players reporting with repeated or long-standing injury of the elbow need to be examined for osteochondritis dissecans of the capitellum and if identified will require surgical opinion. Some evidence suggests that "playing through pain"—commonly seen in handball [44]—can induce osteochondral injury, so it's especially important here for the medical staff to have a good relationship with the players allowing them to feel comfortable in coming forward and reporting symptoms.

A careful history and physical examination is the most important and will be definitive in many cases; however occasionally imaging is warranted where the status of the ulnar collateral ligament is inconclusive and/or osteochondral injury is suspected. In this regard X-ray doesn't appear very useful in aiding differential diagnosis but is usually recommended as an initial screen for rare but serious masquerading sinister pathology. Subsequently ultrasound in good hands does often provide useful clinical information, as does MRI [52]. Note that some "typical abnormal" findings in throwers' elbows can be safely disregarded—hypertrophy, increased bone thickness, lost terminal extension range—but previously investigated athletes may need reassurance during examination at the benign nature of these radiological findings. Anecdotally it's noted that in handball players, lost terminal extension doesn't seem performance limiting, and we note several occasions where vigorous attempts to restore "normal" ROM at the elbow through manual therapy have made otherwise healthy throwers painful.

Once diagnosis is established including co-pathology, management can proceed. In the presence of an intact UCL, rehabilitation needs time to allow for healing of the anterior capsule while increasing strength of the elbow flexors [53, 54]. This strengthening can be commenced early provided full extension or any extension range which induces anterior elbow pain is not reached (which would stress the healing anterior capsule). Similarly, indirect evidence [55] suggests that strengthening the flexor carpi ulnaris and flexor digitorum superficialis can augment resistance to valgus instability, and is therefore routinely commenced early. It's important to establish that there's no occult injury to the flexor pronator mass however; otherwise loading will have to start as remodeling of healing tissue instead of having the aim of hypertrophy of healthy tissue, and parameters (sets, reps, loading) adjusted accordingly.

For valgus extension overload, restoring appropriate shoulder external rotational range of motion is a key treatment goal and is best done considering the individual player's side-to-side difference in humeral torsion [56] before setting treatment goals [57] as the within-player and between player differences are marked in throwing athletes [58].

Typically modern handball players will be familiar with weight training, and the parameters for successful strengthening outcomes need to be considered and tailored to the individual [59]. Aside from volume and intensity, mode of contraction is also a consideration with strengthening interventions where concentric-only exercise can be employed to reduce range of motion, and heavy eccentric exercise can be used to increase range of motion, most likely through a combination of architectural adaptation of muscle fibres [60].

How Does Knowing the Pathology Change Management?

As alluded to above, where a complete rupture of the ulnar collateral ligament is documented, surgical reconstruction is associated with good outcomes [61]; however this rarely appears to be performed in handball, and anecdotal evidence seems to suggest players ultimately often return to the same level with conservative management. If throwing performance is unacceptable however, or the athlete has ongoing interfering symptoms, then a surgical opinion is warranted.

A criteria-based algorithm is proposed for management of goalie's elbow which encompasses throwing-related ulnar collateral ligament injury (Fig. 3.19).

31.4.1 The Importance of an Interval Throwing Program

For each category a key feature is a graded return to throwing via an interval throwing program—(see Fig. 31.20, interval throwing program)—as is an improved understanding on behalf of the player and coach/parent of the importance of throwing load monitoring for injury prevention and performance enhancement.

Handball is a contact sport, and players need to be exposed to contact (i.e., other players, falling to the ground) in a careful graded manner during rehabilitation before resumption of training in an uncontrolled manner can be implemented. Initially progression will start at isometric weight-bearing (closed chain) exercises in a controlled, predictable environment which will then progress to movement from safe ranges into extension and finally uncontrolled, unpredictable outer range movements prior to returning to sports-specific loading.

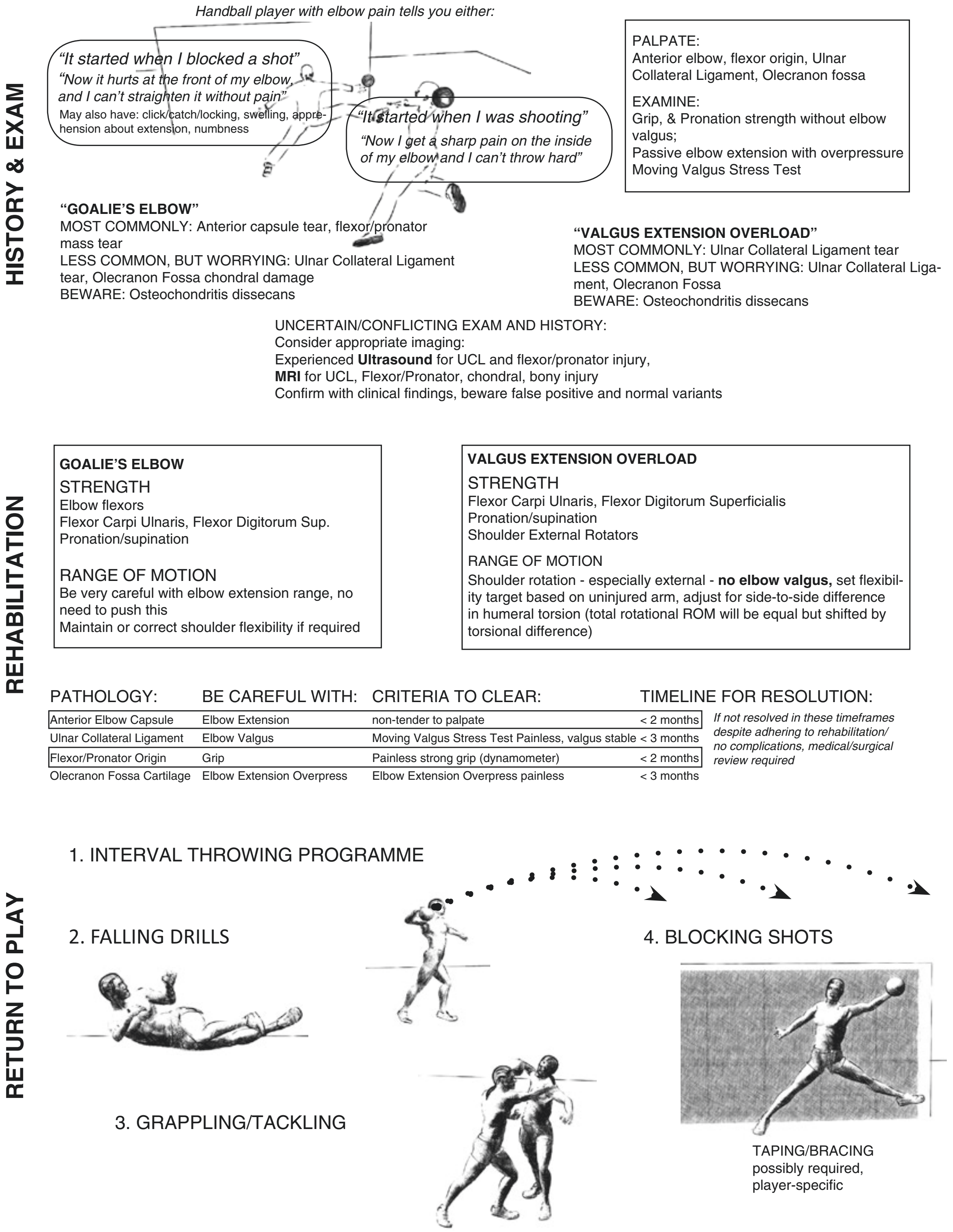
31.4.2 The Role of Taping/Bracing in Injured Players

As with many aspects of the management of handball players, the preventive role of elbow bracing (preventing or limiting elbow extension and valgus) has not been formally investigated but appears to be clinically useful provided the player in question is comfortable wearing the tape/brace. An example is provided of a checkrein taping approach to limit full extension (Fig. 31.21 checkrein taping for the elbow) and can be used as an interim step while resuming sports-specific training or occasionally by players who have completed rehabilitation and are comfortable continuing its application in practice and matches. Note that this taping does appear to limit full extension; however it does not limit varus/valgus to any great extent.

31.5 Implementation of the Kinetic Chain

31.5.1 Background

High-energy activities of the upper extremity like handball throwing are the result of integrated, multisegmented, and sequenced move-



HISTORY & EXAM

Handball player with elbow pain tells you either:

"It started when I blocked a shot"
"Now it hurts at the front of my elbow, and I can't straighten it without pain"
May also have: click/catch/locking, swelling, apprehension about extension, numbness

"It started when I was shooting"
"Now I get a sharp pain on the inside of my elbow and I can't throw hard"

PALPATE:
Anterior elbow, flexor origin, Ulnar Collateral Ligament, Olecranon fossa

EXAMINE:
Grip, & Pronation strength without elbow valgus;
Passive elbow extension with overpressure
Moving Valgus Stress Test

"GOALIE'S ELBOW"
MOST COMMONLY: Anterior capsule tear, flexor/pronator mass tear
LESS COMMON, BUT WORRYING: Ulnar Collateral Ligament tear, Olecranon Fossa chondral damage
BEWARE: Osteochondritis dissecans

"VALGUS EXTENSION OVERLOAD"
MOST COMMONLY: Ulnar Collateral Ligament tear
LESS COMMON, BUT WORRYING: Ulnar Collateral Ligament, Olecranon Fossa
BEWARE: Osteochondritis dissecans

UNCERTAIN/CONFLICTING EXAM AND HISTORY:
Consider appropriate imaging:
Experienced **Ultrasound** for UCL and flexor/pronator injury,
MRI for UCL, Flexor/Pronator, chondral, bony injury
Confirm with clinical findings, beware false positive and normal variants

REHABILITATION

GOALIE'S ELBOW
STRENGTH
Elbow flexors
Flexor Carpi Ulnaris, Flexor Digitorum Sup.
Pronation/supination

RANGE OF MOTION
Be very careful with elbow extension range, no need to push this
Maintain or correct shoulder flexibility if required

VALGUS EXTENSION OVERLOAD
STRENGTH
Flexor Carpi Ulnaris, Flexor Digitorum Superficialis
Pronation/supination
Shoulder External Rotators

RANGE OF MOTION
Shoulder rotation - especially external - **no elbow valgus,** set flexibility target based on uninjured arm, adjust for side-to-side difference in humeral torsion (total rotational ROM will be equal but shifted by torsional difference)

PATHOLOGY:	BE CAREFUL WITH:	CRITERIA TO CLEAR:	TIMELINE FOR RESOLUTION:
Anterior Elbow Capsule	Elbow Extension	non-tender to palpate	< 2 months
Ulnar Collateral Ligament	Elbow Valgus	Moving Valgus Stress Test Painless, valgus stable	< 3 months
Flexor/Pronator Origin	Grip	Painless strong grip (dynamometer)	< 2 months
Olecranon Fossa Cartilage	Elbow Extension Overpress	Elbow Extension Overpress painless	< 3 months

If not resolved in these timeframes despite adhering to rehabilitation/ no complications, medical/surgical review required

RETURN TO PLAY

1. INTERVAL THROWING PROGRAMME
2. FALLING DRILLS
3. GRAPPLING/TACKLING
4. BLOCKING SHOTS

TAPING/BRACING possibly required, player-specific

Fig. 31.19 Algorithm for care of the handball player's elbow. Rehabilitation of the handball player with an injured elbow can be thought of in 3 main sections: History and examination, Rehabilitation, and Return to play. The algorithm outlines suggestions for components of each of these sections, see main body of the text for specific details

Stage	Throws	Distance	Throws	Distance	Throws	Distance
1	15	5m	15	9m		
2	15	5m	30	9m		
3	15	5m	30	9m	15	20m
4	15	9m	30	20m		
5	15	9m	30	20m	15	30m
6	15	9m	30	20m	15	40m
7	15	9m	30	20m	30	40m

Fig. 31.20 Seven-stage interval throwing program for handball. After usual warm-up, begin throwing program. All throws need to be made with no worsening of pain at the time of throwing or the following day. Accuracy is critical; if player cannot usually hit his target within approximately a meter, move back a stage. Each stage needs to be completed painlessly before moving up. Distances given are for adult males. Some players (e.g., younger adolescents) will need to reduce distances proportionately so that the final distances in stages 6 and 7 are close to maximum effort throws. Especially at early stages, take the opportunity to have coaching staff check throwing mechanics—the throwing program is an ideal opportunity to make any corrections in a controlled manner before returning to practice and matches. Note that players will not typically ever throw the longer distances such as those described here in matches or practice, so time should be taken to explain the rationale (progressively increasing throwing intensity) behind this to players and coaching staff

ment of individual joints as well as the action of the muscles [62, 63]. This mutual coordination of different body parts is described as the kinetic chain—simply put—"throwing is not just about the arm." The proper function of the kinetic chain allows the player to generate maximal force and kinetic energy and to transfer it from the lower extremities to the trunk and to the upper extremity during throwing. Individual links of the kinetic chain must be characterized by optimal elasticity, muscle strength and endurance, adequate proprioception, and the ability to perform specific exercises in a repeatable manner. Any failure of the kinetic chain may increase loads exerted on, i.e., structures of the shoulder, leading to pain and microtrauma [62]. During proper functioning of the kinetic chain, lower extremities and the trunk act as force generators, where the shoulder and elbow play a role of a link delivering and regulating generated force. The arm, however, is a part of a mechanism delivering this force directly to the ball [64].

31.5.2 Lower Extremities and the Trunk

Muscles of the lower extremity take part in generating kinetic energy and providing a stable base of support for the movement of distal segments. The stable base forms a foundation for local and global stabilizers of the trunk (abdominal and spinal muscles) jointly responsible for central stabilization, providing dynamic stability of the trunk. Larger muscles, such as erector spinae or abdominal muscles (obliquus externus and internus, rectus abdominis, quadratus lumborum) as well as hip abductors, play a significant role in generating and transferring force and providing stability for the upper extremity function [62]. Lower extremities and the trunk, while providing a stable base for arm movement and torque resulting from pelvis and trunk rotation, generate 50–55% total force and kinetic energy, which can be seen mostly during a tennis serve. Any disruption in the functioning of trunk rotation and weakness of hip abductors and trunk flexors results in a break in the kinetic chain. This may result in an

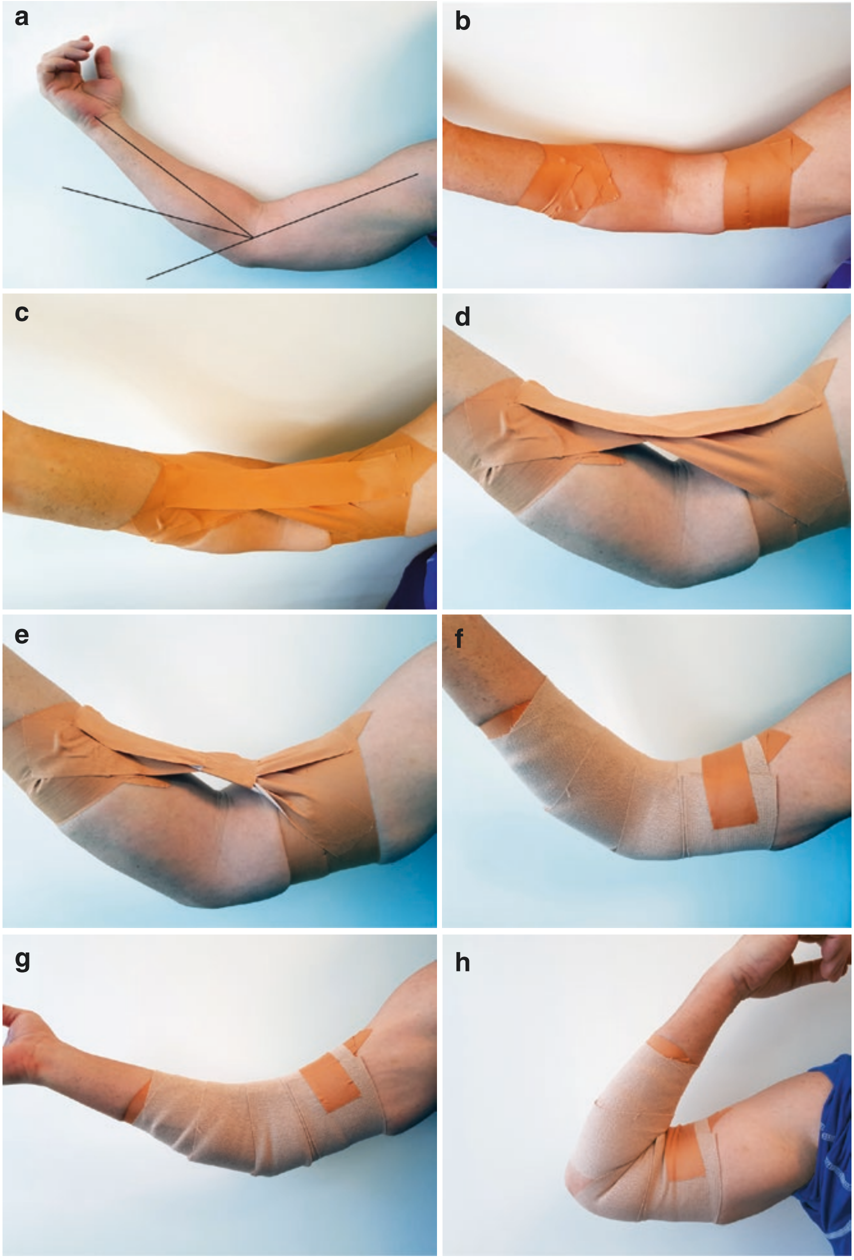


Fig. 31.21 Check rein taping for the prevention of elbow hyper-extension. (**a**) Start with player's elbow approximately 15° more flexed than your intended limit of extension. In this example we are at approximately 145° with the aim of preventing active extension ultimately beyond approximately 160°. (**b**) Using rigid strongly adherent tape (in this case 38mm) place 2 circular anchor straps proximal and distal to the elbow. Note that these need to follow the contour of the arm so that no pleating of the tape occurs. Importantly do not make these strips tight otherwise vascular compromise is possible. (**c**) and (**d**) Place 3 check rein straps from the anchors across the elbow ensuring that the tape doesn't adhere to the underlying anterior elbow. be careful to ensure correct starting elbow flexion position here (**e**) Wrap these 3 check reins together to both slightly tension the tape, and cover the adhesive undersurface of the tape close to the anterior elbow to prevent it sticking during play. (**f**) Loosely cover the entire taping with elastic tape, remembering to close the tape with a small strip of rigid tape (shown proximally here) to prevent unfurling during play. (**g**) and (**h**) Confirm that the elbow range of motion is as desired both to extension and flexion

increase of lumbar lordosis during the acceleration phase which can lead to positioning the arm behind the body. In this way "the slowed down arm" causes excessive abduction and external rotation of the shoulder joint, thus increasing load exerted on anterior and posterior structures of the shoulder joint including the labrum [65–67].

31.5.3 Scapula and Upper Extremity

The scapula has many different functions during a throw. It provides support for the head of the humerus and is an insertion site for muscles that control the movement of the arm and compress the head of the humerus into the socket (rotator cuff muscles, deltoid muscle, biceps brachii, coracobrachialis muscle). The scapula itself is controlled by muscles that stabilize it in relation to the chest (trapezius, rhomboidei, levator scapulae, pectoralis minor, and serratus anterior muscles). Correct function of those muscles allows for proper alignment and stabilization of the scapula in space so that the joint cavity holds the head of the humerus steadily and securely while rotating with high speeds. The scapula has to move fluently into protraction and retraction on the posterolateral wall of the chest, while at the same time the arm changes its position starting from the windup right to the follow-through phase of the throw. Therefore, we may observe scapular movement along with the humerus, maintaining a safe movement zone of the shoulder joint, thus avoiding excessive range of movement in relation to the glenoid [62, 68, 69].

The correct position of the scapula, allowing optimal activation of the muscles around the shoulder joint, is a retraction and external rotation, which is provided mainly by the serratus anterior muscle. It can be obtained by synergistic action of the hip and trunk muscles along with the scapula and the arm. This sequential action ensures maximal activation of the muscles attached to the scapula [70], providing a stable base for the attached rotator cuff muscle [68]. Scapular retraction is an integral part of proper scapulohumeral rhythm during shoulder movements [62]. Disturbances in normal alignment or motion of the scapula are described as scapular dyskinesis. Dyskinesis results from the lack of elasticity of the shoulder joint, weakness of the muscles, or muscle imbalance [66]. The final links of the kinetic chain which generate 36% of kinetic energy transmitted to the ball are the elbow and wrist. Dynamic extension occurring in the elbow provides 21% of the transferred energy of the throw. Simultaneously, it is the most vulnerable segment of the kinetic chain next to the shoulder joint. The remaining 15% of the force and kinetic energy comes from palmar flexion of the wrist.

When one or several segments fail in proper generation and transmission of energy to the next segment of the kinetic chain, load and force distribution is disturbed which leads to the decrease in effectiveness of executed activities. In time, it can cause irritation of the healthy tissue and finally lead to injury. The most frequent proximal causes of dysfunction in distal segments of the kinetic chain (in relation to the surface) include poor sensorimotor control of the feet, range of motion deficit in ankle joints, the shortening or weakness of hip extensors and abductors, restricted movement of the spine and restricted movement and loss of strength of the muscles surrounding pelvis, as well as poor muscle control of the scapula [62, 71].

31.6 Sport-Specific Approach

Providing a comprehensive rehabilitation program for an injured handball player in an athletic environment requires a group effort to be most effective. The rehabilitation process requires communication among a number of individuals (the athlete, the physician, the physiotherapist, the coaches, the strength and conditioning specialist, and the injured athlete's family), each of whom must perform specific functions relative to caring for the injured athlete. This group is intimately involved with the rehabilitative process, beginning with patient assessment, treatment selection, and implementation, and ending with functional exercises and return to activity. The physiotherapist typically directs the post-acute phase of the rehabilitation, and it is essential that the patient understands that this part of the recovery is just as crucial as surgical technique to the return of normal joint function and the subsequent return to full activity. All decisions made by the physician, the physiotherapist, the trainer, and the coaches which dictate the course of rehabilitation ultimately affect the injured player [72].

The rehabilitation should be player-specific: tailored to suit the player's age, position, requirements, physician, and therapists. It is not "accelerated" or "aggressive" or "time-specific." Therefore, any rehabilitation protocol, in case of acute or overuse injury, is a "guide" and not a prescription—there is a delicate and difficult balance that needs to be struck between being overly cautious and too aggressive. Communication between the player, therapists, training staff, and physician are essential, with progression to each phase when the patient is able to perform all of the exercises in the previous phase without any discomfort or apprehension. Each phase is introduced progressively in concert with discussions with all relevant parties so that agreement is reached regarding how carefully or aggressively the rehabilitation should be conducted [73].

Rehabilitation of a handball player, especially at later stages, requires a systematic approach consisting of several steps:

- Conduct a needs analysis of the sport—the basic element before starting working with any athlete. This process consists of answering a number of questions:
  - What movement skills are consistent with the player/position?
  - What muscle groups should be trained?
  - What type of strength qualities are needed for the player?
  - What type of muscle actions (eccentric, concentric, isometric) should be trained?
  - What is the predominant energy system for the sport?
  - What are the primary sites for injury in the sport?
  - What is the injury history of the player?

In the context of a handball player's assessment, the needs analysis has to be tailored to the specific requirements of the player you are examining. Some key points to consider when conducting this are:

- Identify key fitness qualities for the player—identification of the key abilities consistent with the sport, like speed, power, strength, flexibility, anaerobic fitness, etc., which are particularly important for the athlete.
- Perform a functional assessment—identification of any disturbances ("weak links") in the player's kinetic chain, using objective functional tests.
- Perform a fitness assessment—conduction of a battery of fitness tests that are valid for the sport, to determine the player's fitness status.
- Describe a performance profile of the player—based on previously conducted tests to determine their current level of performance.
- Implement a program based upon training age, sport demands, functional and fitness results—if an athlete obtained poor results on functional tests, a program focused on corrective exercises can be implemented along with the rehabilitation process.
- Enhance all strength qualities—proper load management; load adjusted to the player's abilities and stage of rehabilitation.
- Enhance energy system development (ESD)—emphasize speed technique before speed endurance to ensure a more precise technical model is established prior to performing any energy system training.

One of the most important things during the rehabilitation process should be a good cooperation between the athlete, the physiotherapist, and the personal trainer or strength and conditioning coach. Ensuring good communication between all stakeholders minimizes the chance of inappropriately loading the player during the rehabilitation process. Note that this can be both inappropriately overloading and underloading. Overly protective periods in rehabilitation will ultimately underprepare a player for the demands of usual training and matches and can paradoxically contribute to reinjury [74].

31.7 Return to Play

Previous injury is associated with up to a fourfold increase in the risk of reinjury [75], and the treatment of all injuries includes advice on when it is safe to resume sport participation. Even though musculoskeletal trauma represents the majority of injuries in handball, there is little original return-to-play research to help guide practice. In the absence of clear scientific evidence, return-to-play decisions lack standardization [76–78] and can be a source of confusion and disagreement for physicians, athletes, coaches, and administrators [79, 80].

By "return to play," we mean medical clearance of a player for full participation in handball without restriction (strength and conditioning, practice, and competition) [80]. There are a myriad of protocols and guidelines that have evolved after conservative or operative treatment of upper extremity injury to allow a timely return by the athlete to activity and sport. Despite the differences, there are some general principles to consider in the rehabilitation process [81]. The decision model of Creighton et al. [80] (StARRT—the Strategic Assessment of Risk and Risk Tolerance model [82]) is a useful guide to assisting and understanding and optimizing this process (Fig. 31.22). The proposed model was created to clarify the processes that clinicians use consciously and subconsciously when making return-to-play decisions. Providing such a structure provides a logical structure for the return-to-play process with the hope that it will decrease controversy, assist physicians, and identify important gaps in practice areas where research evidence is lacking. The three-step decision-based model comprises health status, participation risk, and then decision modification [73, 83]. First, the health status of the athlete is evaluated, including assessment of symptoms and a battery of analytical and functional tests (e.g., strength and flexibility, throwing performance, etc.). Then, the clinician evaluates the participation risk based on the type of sport, level of competition, and ability to protect the shoulder. Finally, some factors might modify the decision, such as the timing in the season, pressure from the athlete, or his environment [84].

Step 1, Evaluation of Health Status: a complete evaluation of the health status for any particular injury or illness based on history, symptoms, signs, laboratory tests, and functional testing. It requires an assessment of the athlete's recovery from a biological, psychological, and functional standpoint and is done by considering several *medical factors*. This is often based on clinical signs, imaging, and the ability to achieve specific functional tests. In essence, it is an evaluation of how much healing has occurred and how close to "normal" the previously injured tissue is. For the injured handball player, this will likely include physical testing of individual structures (e.g., strength of the shoulder, valgus stress testing of the elbow) along with appropriate imaging of these structures where indicated.

Step 2, Evaluation of Participation Risk: the clinician evaluates the risk associated with participation, which is informed by not only the current health status but also by the sport risk modifiers (e.g., ability to protect the injury with padding and the player's position). These are the factors associated with the sport or activity (sport risk modifiers) that, although not directly related to the evaluation of health status, have the capacity to substantially increase or decrease the participation risk for a given health status. Different individuals are expected to have different thresholds for "acceptable level of risk," and these thresholds will change based on context. In the case of an AC joint-injured handball player, the risk of reinjury is high when resuming full-contact play for a field player, but wearing a protective guard over a non-throwing shoulder may be enough to allow a full participation in a game.

Step 3, Decision Modification: *decision modifiers*, such as timing and season, club and athlete pressures, are considered, and the decision to return to play or not is made. A low risk for an exacerbation of an acute reactive shoulder tendinopathy might be considered unacceptable if the game being considered is a preseason friendly, and the player in question is making his senior debut; however conversely, a high risk of reinjury might be tolerated in the

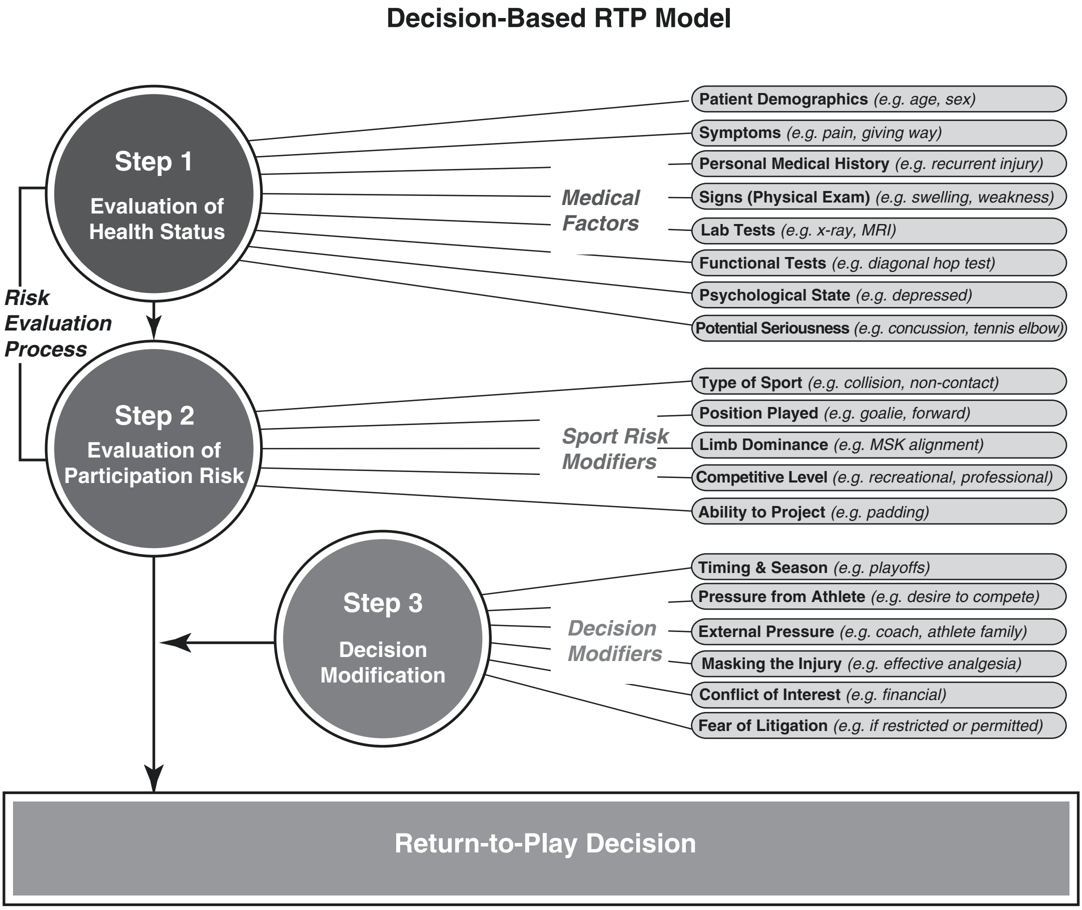


Fig. 31.22 Decision based return-to-play model [80]

case of a team captain playing in a championship final in what would likely be their final appearance. Such modifiers clearly change the decision that would have been made if evaluation of participation risk had been considered alone. Therefore, the clinician's role is to help determine the level of risk, convey this to the player, coach, and significant others, and then collaboratively this group will share both making this decision and owning the consequences, both positive and negative as they arise [80].

Return to play/sport can be viewed as a continuum in parallel with recovery and rehabilitation—not simply a decision taken in isolation at the end of the recovery and rehabilitation process. As injury is an inevitable part of sports participation, optimal contingency planning for return to play/sport might even happen before an injury occurs. In a return-to-play/sport continuum (Fig. 31.23), three elements can be defined, emphasizing a graded, criterion-based progression that is applicable for any sport and aligned with return-to-play/sport goals [85].

- Return to participation. The athlete may be participating in rehabilitation, training (modified or unrestricted), or in sport but at a level lower than his or her return-to-play/sport goal. The athlete is physically active, but not yet "ready" (medically, physically, and/or psychologically) to return to play/sport. It is possible to train to perform, but this does not automatically mean return to play/sport.

Fig. 31.23 The three elements of the return to sport (RTS) continuum [85]

- Return to sport. The athlete has returned to his or her defined sport but is not performing at his or her desired performance level. Some athletes may be satisfied with reaching this stage, and this can represent successful return to play/sport for that individual.
- Return to performance. This extends the RTS element. The athlete has gradually returned to their defined sport and is performing at or above their pre-injury level. For some athletes this stage may be characterized by personal best performance or expected personal growth as it relates to performance.

This is an excellent work and it is an important chapter in the book. I did small comments, nothing major.

The two last chapters, sport specific approach and return to sport could be a bit contracted as they are more general notions and not specific on upper limb.

Could you select your five top references in order to highlight them.

Please add a summary/conclusion sections.

Congratulations and many thanks for your participation.

31.8 Take-Home Messages

- Chronic overload shoulder injuries are multifactorial and should be assessed and treated with special attention to proximal and distal links of the kinetic chain.
- Elbow pain in the handball player is mostly related to forced extension (usually with valgus), and mostly happens in blocking. Conservative care will nearly always allow a return to play, but it's important to establish the pathology as there are some cases where surgical opinion and intervention are required. Careful history then guided physical exam will usually be enough to establish diagnosis which will guide rehabilitation.
- Return to play is a process which begins at the time of injury and involves shared decision-making between all relevant parties and should be thought of as a three-staged process considering initially evaluating the "tissue health," then the risks of participating given this status, and finally modifying factors external to this such as the game and player in question.

Fact Box

While the shoulder and elbow are commonly the sites of pathology for the handball player, these need to be considered as part of a kinetic chain as rehabilitation which is directed only to the tissue or joint involved is likely to fail unless all possible contributors along the chain are managed appropriately during rehabilitation.

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32

Shoulder Assessment in Handball Players

Martin Asker, Rod Whitley, and Ann Cools

As in every body region, a structural and methodical assessment consisting of clinically relevant and valid tests, after an appropriate history, is essential. The combination of the anatomic complexity of the shoulder and the great and varied demands placed on it during handball mean that a deep knowledge of the functional anatomy of the area is critical to understand injury mechanisms, rehabilitation, and return to sport tests. The first part of this chapter focuses on the assessment of the painful/injured shoulder and the second part on the screening/objective measurements of healthy players.

32.1 Assessment of the Injured Shoulder

32.1.1 History

The assessment starts with obtaining a careful history of the player's shoulder problems. History includes injury mechanisms and location, onset, and severity of the pain as well as the presence of any other symptoms than shoulder pain, particularly neck, chest, or arm pain, paraesthesia, and instability. History of previous shoulder injuries is noted, including findings of previous examination, diagnosis, treatments, and rehabilitation. Pay particular attention to identifying injury patterns and recent successful and unsuccessful treatment and rehabilitation interventions.

Most players will be able to describe the situations in which the injury occurred, especially in traumatic and acute injuries. The careful clinician will likely be able to infer a likely diagnosis from the combination of mechanism of injury and presenting symptoms in the majority of cases and subsequently use the physical examination and imaging to confirm this. For instance, trauma to the arm while in throwing position could potentially lead to a "superior labral tear from anterior to posterior" (SLAP) injury or an instability with the former being associated with sharp, localized pain and instability (a feeling the shoulder has "come out"). However, shoulder dislocations or subluxations are

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more commonly seen in the non-dominant shoulder, often caused by fall or during a struggle with an opponent. Similarly, most acute acromioclavicular (AC) joint injuries are caused from trauma directly to the lateral side or the point of the shoulder, and players will describe pain localized to this area. For more longer-standing shoulder problems, often related to throwing, establishing when the shoulder hurts during the throwing motion is important and also how the shoulder problems affects the sport and level activity. Many players have regular or intermittent shoulder pain and tend to seek medical care only when their performance is affected. Often the player describes a pain either in the deceleration phase or in the cocking or acceleration phase. Usually, when pain occurs after ball release, players can still throw at maximum speed when required, while pain during the cocking and acceleration phases is associated with reduced throwing velocity which the player might describe as a “dead arm”. For atraumatic injuries, it is also very important to identify any triggers of the onset, e.g. increased throwing, new shoulder exercises, or other increased load on the shoulder, since this would be a key factor to address in both rehabilitation and future prevention strategies. For characteristic history and clinical findings for the most common shoulder diagnosis in handball (see Table 32.1).

32.1.2 Assessment Routines

It is important to have a certain routine during the assessment since it facilitates clinical reasoning and minimizes the risk of missing something if you always have to think of what to do next. The tests must be chosen based on the history—this helps minimize the risk of unnecessary provocation of the symptom and false-positive testing. In the very acute phase, it can sometime be very hard to get any reliable results from the examination, since in many cases, everything hurts. In these cases, a new assessment is required after things have settled down, and the initial assessment will likely be limited to ruling out some diagnoses and settling on a cluster of likely pathologies for later confirmation.

It’s suggested that the assessment routine for the shoulder includes (1) inspection, (2) exclusion of neck-originated pain, (3) active movements, (4) passive movements, (5) resisted movements, (6) palpation, (7) orthopaedic tests, (8) symptom modification procedures, and (9) shoulder function/performance assessment (if possible, due to pain). The order of these can be tailored to your preference; however, maintaining a preferred routine will make it unlikely that your assessment will be incomplete. Note that in some cases, some aspects will not be warranted given the history or other findings. The algorithm below can serve as a base for clinical reasoning around the painful shoulder in handball players (Fig. 32.1).

32.1.3 Inspection

The examination begins with an inspection of the player from both the sagittal and frontal planes. The inspection includes checking general posture, shoulder position, and muscle atrophy. Since handball players adapt to the handball game, some findings are common in uninjured players as well, e.g. more rounded shoulder posture on dominant side and scapula position, so these findings should be interpreted carefully and always be based on clinical relevance [1, 2]. Other observations such as atrophy of the posterior cuff or joint protuberances or displacement of sternoclavicular (SC), AC joint, or the shoulder joint are also noted as well as any swelling.

Fact Box

Have in mind that some findings during inspection and active movements are common in handball players, since the players adapt to the sport. More rounded shoulder posture, altered scapula position, and altered range of motion are common in the dominant shoulder in handball players, and these findings should be interpreted carefully and always based on clinical relevance.

Table 32.1 Characteristic history and clinical findings for the most common shoulder diagnosis in handball

	History	Clinical findings
Rotator cuff tendinopathy	Often complains of pain during throwing especially in the deceleration phases. Pain after loading the shoulder, e.g. high frequency of throwing or lifting the arm above the shoulder	Positive full can. Pain during resisted ER, especially during the "break test". Sometime only painful post-contraction. Pain at palpation over the greater tuberosity of the humerus
Rotator cuff rupture	Often, older players with a specific, painful onset. Significant weakness in ER and/or abduction with ER (supraspinatus/infraspinatus) or IR (subscapularis). Night pain	Positive ERLS and drop arm test (supraspinatus/infraspinatus). Positive IRLS/belly press test (subscapularis). Typical loss of active abduction/ER ROM. Passive ROM often not a problem unless too much pain or swelling. Imaging usually conclusive (MRI, US)
Biceps tendinopathy	Pain in the anterior part of the shoulder during throwing, overhead activity, or biceps contraction. Sometime clicking. History often reveals an increase in throwing or overhead weightlifting	Pain at palpation of the bicipital groove. Positive Speed test and forward flexion from extended position. For extraarticular tendinopathy, ultrasound is very useful; for insertion-related tendinopathy, MRI should be performed
SLAP lesion	Pain deep in the shoulder during throwing or loading with maximal external rotated shoulder or excessive traction of the shoulder. Often a specific onset in the same situation as describe above. Clicking in the shoulder and sensation of instability might also be present	Positive battery of SLAP lesion test including O'Brien test, apprehension, biceps load II test, passive compression test, and the resisted supination external rotation rest. MRI arthrography is the examination of choice to confirm the diagnosis
External impingement	Most often pain-free in activities below 90° abduction or flexion. Pain, located anteriorly, is aggravated in internal rotation and horizontal adduction. Sometime night pain	Positive Jobe test, Hawkins-Kennedy test, Neer test. Positive symptom modification procedures (e.g. SAT, SRT) indicate a secondary impingement
Internal impingement	Pain located posteriorly in the shoulder and provoked in cocking phase during throwing or at maximal external rotation. Often not that troubling during night	Pain during apprehension test and positive relocation and release test. Pain during maximal external rotations
Instability	History of trauma with dislocation (TUBS) or sensation of instability (AIOS or AMBRI) often during throwing or overhead activities with external rotation movements. Complains of "dead arm syndrome". Important to ascertain presence of neurological deficit with "dead arm"—absence implicates SLAP/inside impingement, and presence suggests instability. Often, secondary problems with cuff tendinopathy or secondary impingement	Positive apprehension test, relocation test, and release test. Discomfort during load and shift and/or sulcus sign. For posterior instability, the posterior subluxation test is positive. In case of a traumatic instability, i.e. dislocation of the shoulder, secondary injuries such as Bankart lesions and Hill-Sachs lesions are often present
AC joint injury	History of trauma to the point of the shoulder or trauma with the arm maximal abducted or horizontal adducted. Pain located at the top of the shoulder during abduction that gets more intense the more elevated the arm gets. Painful lying on the shoulder and elevation above 90°	Positive cross-body test and Yocum test. Distinct pain when palpating the AC joint and often palpable and visible malformation in grade II or III injuries

AIOS acquired instability due to overstress syndrome, *AMBRI* atraumatic often multidirectional with bilateral laxity, where first choice of treatment is rehabilitation and second choice is inferior capsular shift surgery, *ER* external rotation, *ERLS* external rotation lag sign, *IR* internal rotation, *IRLS* internal rotation lag sign, *MRI* magnetic resonance imaging, *SAT* scapula assistance test, *SLAP* superior labral tear from anterior to posterior, *SRT* scapula retraction test, *TUBS* traumatic unidirectional instability with Bankart lesion, which often needs surgery, *US* ultrasound

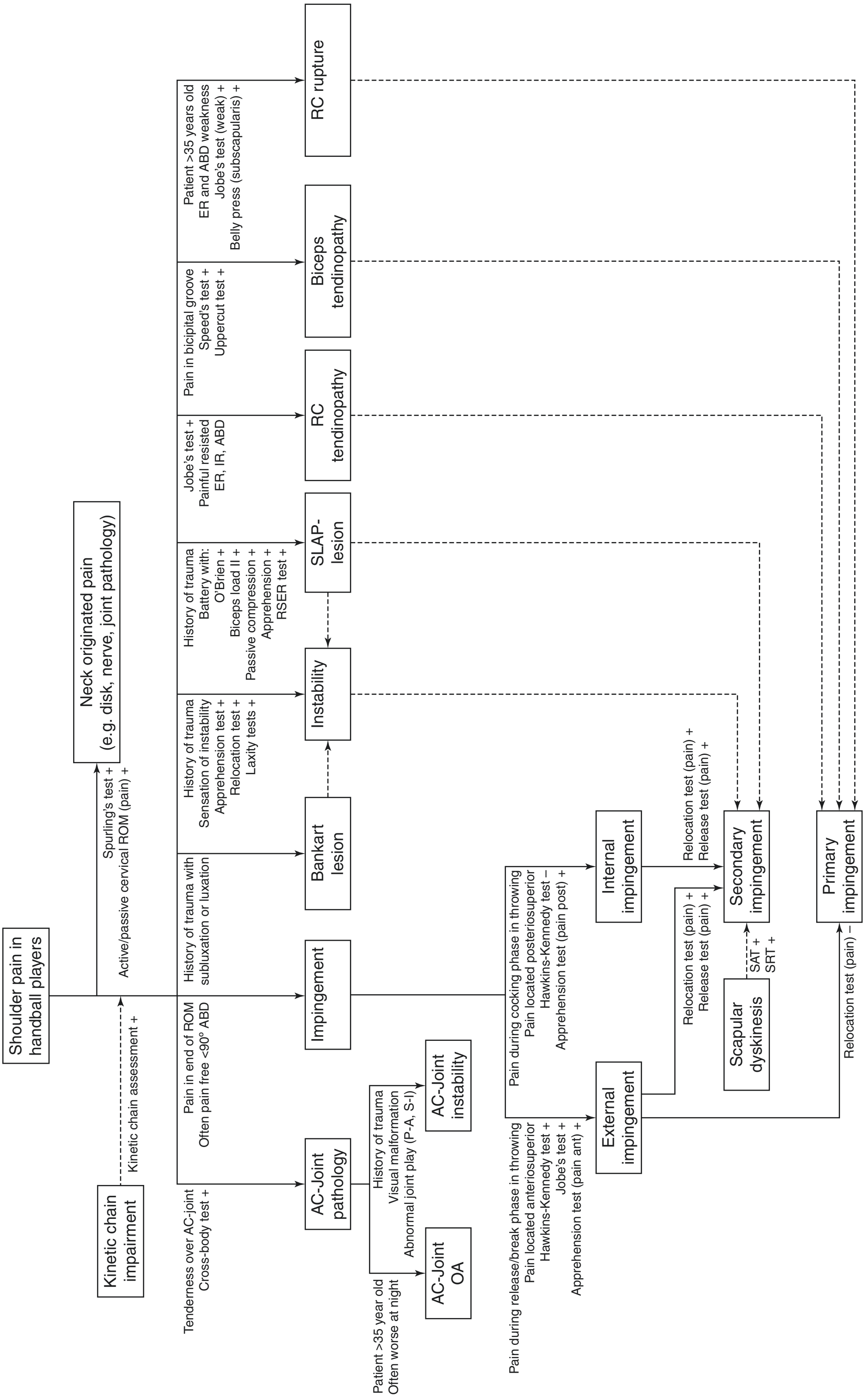

Fig. 32.1 An algorithm for clinical reasoning around the painful shoulder in handball players

32.1.4 Excluding Neck-Originated Pain

Occasionally players can present with shoulder pain, which is cervical in origin. Symptoms will not be “typical” for shoulder pathology and may include paraesthesia, as well as pain radiating to areas other than the shoulder. A basic examination includes active and passive neck movements and preferably the Spurling test, consisting of a combination of maximal rotation, lateral flexion, and extension of the cervical spine or until any reproduction of the player’s pain. This test is considered positive for nerve root pathology if it produces any radiating pain or discomfort in a specific dermatome of the ipsilateral upper limb. If any of these neck procedures reproduce the player’s problems, this should be considered a primary neck-originated problem with more or less secondary shoulder problems or in some cases a combination of both neck and shoulder pathologies with mixed symptoms. If the basic examination described above reveals any positive findings, the cervical spine should be further tested, including test for the cervical and brachial plexus and its associated peripheral extensions. If the history includes any radiating pain or if any test during the assessment produces such, nerve tension tests of the upper limb should also be performed.

32.1.5 Active Movements

Have the player perform active forward flexion, extension, abduction, external rotation (ER), and internal rotation (IR) to assess range of motion, pain, and quality of the movement. If any restriction or pain appears, note where in the range of motion it occurs, and ask the player if this pain is the same as their primary problem or different. Altered scapular movements (scapular dyskinesis) may be noticed during these motions, especially during forward flexion and abduction. Our understanding of the relation between alterations in scapular kinematics and shoulder pathology has continued to evolve since Kibler’s original work drew attention to its importance [3, 4]. Three different patterns of dyskinesia have been described by Kibler: type (1) where a prominent inferior angle of the scapula is seen, (2) where a prominent medial border of the scapula is seen, and (3) where a prominent superior angle of the scapula is seen. If unloaded movements are equivocal, for senior and older junior players, often some extra resistance, e.g. a 1–2 kg dumbbell, or more rapid movements are needed to reveal a scapular dyskinesis. Some research has shown a poor association between assessment of scapular position and present [5] or future shoulder pain [6] in overhead athletes and difficulties in accurately quantifying scapular position [7] and large between-subject variability for even the simplest movements [8]. Recently, however, a study of young elite handball players showed that those with scapular dyskinesis were less tolerant to high increase in training and match doses. However, if the increase in match and training dose was below 20%, it did not matter if the player had scapular dyskinesis or not [9].

32.1.6 Passive Movements

This includes the same motions as in active range of motion (ROM), and comparison between the range of motion and motion quality in active versus passive movements is performed. If a player shows restricted active ROM or impaired motion quality but no restriction is found during passive ROM, it is more likely that the impaired motions seen during active movement are due to lack of control or strength rather than lack of tissue extensibility. Evaluate the end feel in each movement, and notice any specific pattern of lack of motion (e.g. gradual stiffening during range compared to an abrupt block) and the reports of the patient (“tightness” versus painful limitation of range). More specific tests to measure internal and external ROM are suggested and described in the shoulder screening section.

32.1.7 Resisted Movements

Resisted movements in a painful shoulder are preferably done with the shoulder in less stressful positions for shoulder flexion, extension, abduction, adduction and internal and external rotation, and elbow flexion and extension (see Figs. 32.2, 32.3, 32.4, 32.5, 32.6, and 32.7). If the player has subtle problems though, strength should be tested in a more sport-specific position, e.g. throwing position, so-called 90–90, to more easily provoke pain. Check for pain and any weaknesses but also co-contraction of other areas. A painful test, and sometimes the pain only appears post-contraction,

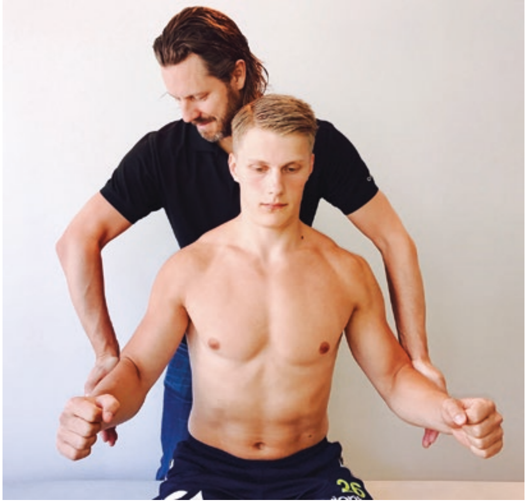

Fig. 32.2 Resisted abduction

Fig. 32.3 Resisted adduction

Fig. 32.4 Resisted external rotation

Fig. 32.5 Resisted internal rotation

Fig. 32.6 Resisted elbow flexion

Fig. 32.7 Resisted elbow extension

without any strength impairment, indicates a tendinopathy. Weakness without or with very little pain indicates larger rotator cuff rupture or nerve pathology.

32.1.8 Palpation

Palpation is best done in a sitting or standing position to allow assessment of anterior and posterior structures including the SC joint, the clavicle, the AC joint, the coracoid process, the greater and lesser tubercles of the humerus, the posterior part of the glenohumeral joint, and the sulcus in between these containing the biceps tendon, as well as the rotator cuff muscles and tendons. To be able to palpate the supraspinatus tendon, the shoulder needs to be internally rotated. Try to narrow down the area with maximal tenderness, and it's useful to palpate bilaterally simultaneously where possible to avoid false-positive findings. Also note any tenderness in surrounding muscles such as trapezius, levator scapulae, pectoralis minor and major, and rhomboid muscles. In the handball player, pain on the coracoid process could be related to a hypersensitive pectoralis minor or pectoralis minor tendinopathy (medial to the coracoid) and far less commonly coracobrachialis or short head of biceps (inferiorly and laterally respectively), while pain in the bicipital groove could be a sign of irritation of the synovial sheet or tendinopathy of the long head of biceps. Further, provoked pain in the posterior part of the glenohumeral joint is relatively commonly seen in players with posterior impingement, with specific palpation tenderness of the infraspinatus muscle, and sometimes also as a sign of SLAP. Notable, as with any clinical test, the interpretation of the findings must be done with consideration of the player's description of the shoulder problems and the findings from other provocation tests. As many of these areas are typically uncomfortable to palpate in the absence of any pathology, it's useful to palpate both the healthy and injured sides simultaneously, and rather than asking the athlete "does this hurt?", ask if there is more pain on one side than the other.

32.1.9 Orthopaedic Tests/ Specific Test

After the basic assessment of movement and palpation, orthopaedic tests are performed. These tests can be considered to be symptom provocations rather than specific structural diagnostic tests since the specificity for many of the orthopaedic tests is questionable. Many tests have shown not to be clinically predictive for a specific injury, and the latest evidence suggests that test combinations should be performed instead of single tests [10]. A summary of the clinical value of the tests described below is presented in Table 32.2.

32.1.9.1 Tests for Shoulder Laxity and Instability

When assessing the stability of the glenohumeral joint, it is necessary to recognize that a great laxity or joint play does not imply instability and vice versa. The laxity describes the amount of translation in the different directions in the shoulder, while instability is the patient's perceived feeling of not being stable in the joint which could be due to lack of motor control or strength in the shoulder as well as mechanical instability. Instability is often categorized into three different types, depending on the cause of the instability: AIOS (acquired instability due to overstress syndrome), AMBRI (atraumatic, often multidirectional with

Table 32.2 Clinical value of selected shoulder tests

Assessment	Sensitivity	Specificity	Positive test/findings
Instability			
Apprehension	66	95	Apprehensive feeling
Relocation test	65	90	Reduction of apprehension
Release (surprise) test	82	86	Surprise apprehension
AC joint pathology			
Cross body	77	79	Identical pain over the AC joint
AC joint tenderness (palpation)	96	10	Identical pain over the AC joint
Impingement			
Hawkins-Kennedy	80	56	Identical pain anterior superior
Neer test	72	60	Identical pain anterior superior
Yocum test (for subacromial impingement)	79	40	Identical pain anterior superior
Internal impingement (apprehension position)	76	85	Identical pain posterior superior
Rotator cuff pathology			
Full can	59–89	54–82	Weakness and/or pain
Internal rotation lag sign (subscapularis tear)	100	84	Weakness and/or pain
External rotation lag sign (rotator cuff tear)	56-100	93–98	Weakness and/or pain
Belly press test	80	88	Weakness and/or pain
Drop sign	73	77	Weakness/inability to lower the arm from fully abducted
Labral injuries and biceps pathology			
Speed (biceps pathology)	50–54	60–81	Identical pain over the biceps groove
Uppercut test (biceps pathology)	73	78	Identical pain over the biceps groove
Uppercut test + bicipital groove tenderness (biceps pathology)	88	94	Identical pain over the biceps groove
O'Brien/active compression test	59–94	28–92	Identical pain deep in the shoulder
Passive compression test	82	86	Identical pain and/or clicking deep in the shoulder
Biceps load II	30	78	Identical pain deep in the shoulder
Resisted supination external rotation	83	82	Identical pain and/or clicking deep in the shoulder
Apprehension + speed + compression−rotation	25	92	Identical pain deep in the shoulder

Table based on Hegedus et al. [10], Chronopoulos et al. [11], Walton et al. [12], and Rosas et al. [13]

bilateral laxity, where the first choice of treatment is rehabilitation and second choice is inferior capsular shift surgery), and TUBS (traumatic unidirectional instability with Bankart lesion, which often needs surgery).

Two common tests to assess laxity in the shoulder joint are the load and shift, for anterior and posterior translation, and sulcus sign for inferior translation. In the load and shift test, the player is seated, and the examiner fixes the humeral head with one hand and the clavicle and scapula with the other hand. Thereafter the humeral head is centred in the glenoid (load) by pushing it into the glenoid in the scapular plane, and then the humeral head is pushed anterior and posterior (shift). The translation can be graded as (1) grade 1, translation to the glenoid rim; (2) grade 2, translation over the rim with a spontaneous relocation when the examiner lets go of the humeral head; and (3) as grade 2 but without the relocation (see Fig. 32.8).

Inferior laxity is tested with the player seated and the examiner fixating the scapula with one hand and with the other hand fixating just proximal to the elbow. The arm is then pulled downward to create traction, and a sulcus can be seen in the presence of inferior instability (sulcus sign). This can also be done with the shoulder externally rotated, which tightens the coracohumeral ligament (which prevents lateral translation of the humeral head) [14]. A sulcus sign or replication of the player's symptoms (typically "going out") is suggestive of symptomatic inferior instability (see Figs. 32.9 and 32.10). As mentioned, these tests only assess the player's laxity, which might have little to do with their injury, especially when found bilaterally. Further, when evaluating these findings, one must also consider the general physiological laxity of the players, which could be measured with the Beighton score. Instead if the player describes that, e.g. "this is the feeling (instability) I have when I am throwing!", this is

Fig. 32.8 Load and shift test

Fig. 32.9 Sulcus sign in neutral position

Fig. 32.10 Sulcus sign with externally rotated arm

more clinically relevant than just the degrees of translation.

Players describing an unusual weakness during and after collisions or falls, fending other players off, or during heavy bench press should be suspected to have posterior instability and examined accordingly. To test for posterior instability, the load and shift is performed posteriorly as described above; however, since posterior instability in these athletes can be associated with high-energy collisions, the load applied in this manoeuvre is often insufficient to replicate their symptoms. Additionally a posterior instability test or jerk test can be performed. With the player in a sitting position, the examiner stabilizes the scapula with one hand and with the other hand on the player´s elbow places the player's shoulder in 90° elevation in the scapular plane and then applies an axial load along the humerus. While doing this, the examiner then internally rotates the arm and moves the arm in horizontal adduction. A positive test is indicated if the player feels any discomfort (apprehend) or resists further motion of the arm due to discomfort. This test can also be performed in the reversed direction, starting with the arm fully horizontal adducted. In this position, the examiner again applies an axial load to the shoulder, which in the unstable shoulder causes a subluxation posteriorly, and then the examiner moves the arm in horizontal abduction. When the shoulder reaches round the scapular plane, a reposition of the shoulder could be felt and often seen as a "jerk" which indicates a positive test. However, in muscular athletes such as handball players, it could be hard for the clinician to provoke the instability, and therefore we suggest an additional test, the "posterior instability stress test". Here the examiner can augment the posteriorly directed load with their body weight by pushing through the line of the humerus from their pelvis while simultaneously checking for a variety of ranges of motion—rotating, flexing/extending, and horizontally adducting/abducting (see Video 32.1).

The most common test to assess anterior instability is the apprehension test or fulcrum test. This test is described with the player in supine position, and the examiner elevates the arm and externally rotates it to the 90–90 position. The arm is then slowly pushed posteriorly. For more provocation, the examiner can pull the humeral head anteriorly (fulcrum test). If the player is apprehensive or describes a feeling of subluxation, the test is considered positive (see Fig. 32.11). If pain occurs anteriorly/superiorly, this indicates a subacromial pain or external impingement, while pain at the back of the shoulder indicates an internal impingement or posterior impingement. While in the apprehension test, the examiner can push the humeral head posteriorly, called the relocation test. This would create a posterior translation of the humeral head, and if the feeling of subluxation disappears, the test is found positive for anterior instability. However, when pushing the humeral head posteriorly in this position, the scapula will also move, in this case in creating relative shoulder horizontal adduction which would lead to lesser scapula-humeral angle and lesser compressive stress on the posterior labrum, joint capsule, and rotator cuff. Therefore, pain reduction during the relocation test does not necessary mean that the shoulder is unstable, but is instead a sign of internal or posterior impingement. During the relocation test, the examiner can quickly let go of the posterior pressure, called the release or surprise

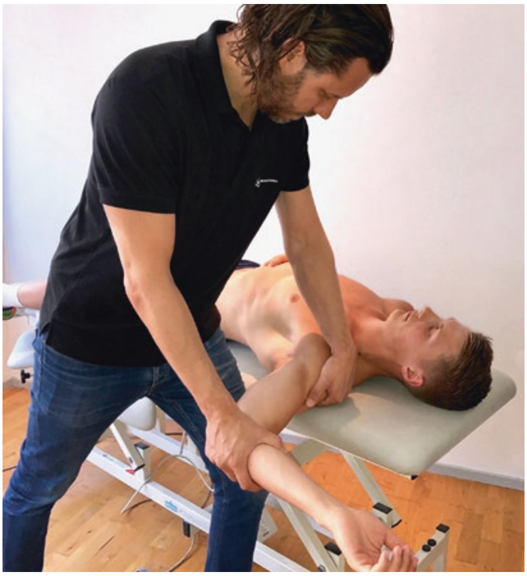

Fig. 32.11 Apprehension test

test. Any reproduction of the player's symptom, i.e. being apprehensive or describes a feeling of subluxation during this procedure, is considered as positive for an anterior instability.

It has been suggested that the apprehension test should be done with the arm in 90° abduction, but most players throw with the arm more elevated than the 90° or do "under head" throws with the arm at the waist, and also, high stress is commonly put on the non-dominant arm in other position than just 90° abduction. Therefore, we suggested that this test should be performed with the arm from 45° abduction to at least 160° to cover the full potential range where instability may be present. Further, the affected player can often pinpoint the position where they feel their instability or pain, which could guide the examiner to narrow down the range where instability would be present.

32.1.9.2 Tests for AC Joint Pathology

Acromioclavicular injuries can occur when the player falls either on their outstretched arm or more commonly with direct trauma to the lateral side of the shoulder. It is important to identify any AC joint disruption after a trauma. In the acute case of disruption, any presence of instability should be assessed. In the subacute cases of disruption, pain is often the only symptom, and instability is usually not present. If possible, mindful of the player's pain, assess joint laxity in superior/inferior (coracoclavicular ligaments) and posterior/anterior (acromioclavicular ligaments) directions.

Often, a player's symptoms can be replicated, and the diagnosis confirmed with careful bilateral firm palpation of their AC joints. Note that it's important to palpate the entire length (anterior through to posterior) and ask the player if the injured side feels painfully different to the uninjured side. Simply palpating the injured side and asking if it hurts will result in many false positives. The player often complains about pain on the top of the shoulder and typically in the end of range of abduction, flexion, extension, or horizontal adduction, i.e. the cross-body test (see Fig. 32.12), or a combination of flexion and horizontal adduction (Yocum test) (see Fig. 32.13). During the Yocum test,

Fig. 32.12 Cross-body test

Fig. 32.13 Yocum test

the player could either experience pain on the top of the shoulder which would indicate AC joint pathology or pain more anteriorly or laterally of the shoulder (subacromial pain) or feel a restriction of ROM which would indicate a restriction in the posterior rotator cuff and posterior joint capsule. With the player in a sitting position, the examiner performs an AC joint shear test. During this test, the examiner compresses the AC joint by pressing the clavicle with one hand and the spine of the scapula with the other hand (see Fig. 32.14). A positive test includes abnormal movement of the AC joint felt under the examiner's hand, sensation of instability, and/or pain.

32.1.9.3 Tests for Impingement Syndrome

Impingement should be considered as a symptom, which could be caused by different underlying pathologies rather than a diagnosis itself. Impingement can be divided into external (subacromial) or internal (glenoid) impingement. As described before, pain in the anterior/superior aspect of the shoulder suggests an external impingement syndrome, and pain located in the back of the shoulder indicates an internal impingement syndrome. Internal impingement is more often the case in the younger player, while the external impingement or a combination of internal and external impingement is more often seen in the senior players. Further, impingement can be divided into primary or secondary impingement syndrome. Primary impingement means that the symptoms are more likely linked to a structural cause, e.g. rotator cuff tear or tendinopathy, or reduced subacromial space due to the shape of the acromion and the coracoacromial ligament. Secondary impingement means that the symptoms are more likely linked to a functional cause, e.g. joint instability, strength, or motor control impairment of the shoulder girdle. The secondary impingement is more commonly seen in the younger players, while in the older players, primary impingement is found.

The most common tests for the external impingement are the Hawkins-Kennedy test and the Neer test (see Figs. 32.15 and 32.16). These tests aim to reproduce the player's pain by narrowing the subacromial space. The Neer test is described as a test including diagnostic injection into the subacromial space. However, in handball players, acromioplasty is rarely indicated, and rehabilitation is always the first-line care. The internal impingement can often be provoked with the apprehension test described above. Reproduction of the pain located posteriorly in the shoulder is considered as a positive test.

Fig. 32.14 AC joint shear test

Fig. 32.15 Hawkins-Kennedy test

Fig. 32.16 Neer test

32.1.9.4 Tests for Rotator Cuff Pathologies

Players with rotator cuff tendinopathy often complain of shoulder pain during throwing or loading the shoulder during rotations or abduction. Often they will describe a feeling of difficulty warming up for throwing. Extension and adduction are often more pain-free. To identify cuff pathologies, isometric contraction in different movements as described above can be useful. Pain may rarely be provoked with palpation or percussion over the greater tuberosity. Specific tests include the “full can” test which involves isometric abduction in the scapular plane with the forearm supinated (thumbs up) and the “empty can” test (Jobe test) with the forearm pronated and may give some guidance, distinguishing between impingement and tendinopathy (see Figs. 32.17 and 32.18). If the “empty can” test is painful but no pain is provoked during the “full can”, pain is more likely to be impingement related rather than tendon related.

Mercifully, rotator cuff ruptures are extremely rare in younger handball players and very unusual in older players. A history of a “pop” and sudden weakness during activity, particularly where use of anabolic steroids are suspected or in an older player with a long history of shoulder problems. Several tests have been described to identify rotator cuff ruptures, but given their rarity in this population, they won’t be further discussed here, but the interested reader is directed to Hegedus et al. for a review [10].

Fig. 32.17 Full can test

Fig. 32.18 Empty can test

32.1.9.5 Test for Superior Labral Injuries/SLAP and Biceps Pathology

The labrum and the tendon from the long head of biceps are highly integrated with each other where the tendon attaches to the superior part of the labrum. Handball throwing and the frequently close contact and struggle with opponents create a great load and stress on this area. Several tests for SLAP and biceps pathologies, which are more or less reliable and valid, have been described in the literature. The O´Brien test, the biceps load II test, the passive compression test (crank test), and the resisted supination external rotation test have all shown to have clinical value in diagnosing SLAP injuries [10, 15]. In the O'Brien test, the player is standing with the arm forward flexed to 90° and horizontal adducted 10° with the forearm pronated. In this position, the examiner stabilizes the shoulder and upper arm with one hand and then presses the arm towards the floor with the other hand, while the player resists. The same procedure is then repeated with the forearm fully supinated. Importantly, the shoulder should be kept in the same position, and only pronation and supination of the forearm should be performed (therefore altering tension on the biceps), hence the importance of the fixation of the shoulder or elbow during the test (see Video 32.2). The test is considered positive for SLAP lesion if the pain or pain and clicking described inside the shoulder are provoked with the forearm pronated and then significantly reduced when the test is repeated with the forearm supinated. When pain is elicited during the test, it is important to localize it as it may have different interpretations. The O'brien's test may provoke AC joint pain in the presence of AC joint pathology. If a posterior shoulder pain is elicited, posterior labral lesions should be suspected [16].

During the biceps load II test, the player is lying supine, while the examiner puts the shoulder in the apprehension position, i.e. 120° shoulder abduction, maximum external rotation, 90° elbow flexion, and forearm fully supinated. In this position, the player is instructed to apply resistance, while the examiner tries to extend the elbow, i.e. biceps contraction (see Video 32.3). The test is considered positive if pain or instability is reproduced during the contraction. In the speed test, the player is resisting downward flexion from 90° forward flexion with the forearm supinated (palm up) (Fig. 32.19). Pain reproduced in the biceps region is considered as a positive test. The same procedure could be performed with shoulder in 45° flexion and flexed elbow (uppercut test), which could potentially put a greater stress to the biceps tendon and together with a positive biceps groove pain provocation that distinguished biceps tendinopathy to SLAP injuries [13] (see Fig. 32.20).

Fig. 32.19 Speed's test

Fig. 32.20 Uppercut test

In the passive compression test, the player is in supine or side-lying position with the arm elevated in the scapular plane. In this position, the examiner applies an axial load to the humerus while externally and internally rotating the shoulder. Make sure to cover the total range of motion, going from slightly abducted all the way up to 160° abduction. A positive test for labral tear (Bankart or SLAP) is considered if identical pain is reproduced, especially with a click during the rotation (see Video 32.4). In the same position, the resisted supination external rotation test is performed (see Video 32.5). In this test, the player is in supine with the shoulder abducted to 90°. The examiner fixates the player's forearm in neutral with the elbow flexed 65–70°. The player is then instructed to supinate the hand, while the examiner resists the supination and also rotates the shoulder. The test is considered positive if this reproduces pain or clicking deep in the shoulder. Importantly, this could also produce pain in the posterior part of the shoulder, which, without clicking, should not be considered as a positive test.

32.1.10 Symptom Modification Procedures

Once the orthopaedic tests are completed, shoulder symptom modification procedures can be performed. These series of procedures are adjunct to the tests above with the aim to evaluate the functional aspect in different parts of the kinetic chain of the present shoulder problems and serve as guidance in prognosis and management of the condition [17]. This procedure can involve correction of posture, trunk stability, scapular or humeral head positioning, and assistance, but the general principles are the same regardless of what specific test is used. First the position, strength tests, or movement that reproduces the symptoms is identified. Secondly, functional adjustments are performed, e.g. scapular stabilization, and then finally, the first step is repeated, and any changes in symptoms are noted. The basic procedure presented below includes manual involvement from the examiner; however, many times the most provocative movement for the player is throwing, and therefore both tape and orthoses could be used as a symptom modification procedure as well as active correction.

During the scapular assistance test, the player is ask to perform the movement that provokes the pain, often abduction of the arm, and then relax. The examiner then assists the scapula by gently putting one hand as a support in the upper part of the scapula and the other hand on the inferior angle. The player then performs the same movement, while the examiner assists the movement (see Video 32.6). If the symptoms are relieved, the test is considered positive [4].

If isometric contraction produces identical pain, the scapula retraction test and humeral head test can be performed. After isometric contraction, the examiner retracts the scapula by fixating the coracoid process with the hand and pushing the scapula against the thorax. The isometric contraction is then repeated (see Video 32.6). The same procedure can be used to position the humeral head in the glenoid and then retest in the same direction that aggravates the symptoms.

The involvement of the thoracic posture can be assessed in similar way. First the painful movement is performed, and then the player is instructed to extend the thoracic spine and then perform the same movement again. Notably, as mentioned in the introduction, in the acute phase, the shoulder could be too painful for any symptom modification procedures, which not necessarily mean that the scapular control or kinetic chain is not involved in the present shoulder problem. In this case, a new assessment should be performed when the most acute problems have settled.

Fact Box

Symptom modification procedures are a series of adjunct tests, perfomred in addition to the orthopaedic tests (symptom provocation tests), with the aim to evaluate the functional aspect in different parts of the kinetic chain of the present shoulder problems. The findings from these procedures serve as guidance in the prognosis and management of the condition.

32.2 Diagnostic Imaging of the Shoulder

As an adjunct to the physical assessment, diagnostic imaging can be used. Since many "abnormal" findings can be seen in the uninjured handball shoulder [18], the interpretation of such should be in relation to clinical signs and the player's history, and imaging should not be performed as a “fishing expedition” without a clear indication.

32.2.1 Radiography (X-ray)

Plain film radiography can be useful to identify glenohumeral and AC joint arthritis or dislocations, fractures, calcification of any cuff tendons, and configuration of the acromion and the acromiohumeral interval. In the youth players, it is also possible to detect any widening of the proximal humeral physis (“little league shoulder”) [19].

32.2.2 Magnetic Resonance Imaging (MRI)

MRI has a long been the study of choice for imaging of the shoulder because of its ability to detect numerous types of pathologies. With MRI, bursitis, tendinosis, biceps pathologies, and cuff tears can be demonstrated. Further, signs of instability (e.g. labroligamentous injuries, bony Bankart and Hill-Sachs’ lesions), signs of internal impingement (e.g. posterosuperior labral pathologies), signs of SLAP, and AC joint pathologies can also be assessed with MRI [18]. For better imaging of labral tears though, MR arthrography is recommended.

32.2.3 Arthrography

This is useful for obtaining a detailed image of the soft tissues around the shoulder joint such as the labrum and joint capsule. It can also be useful to detect smaller Bankart and Hill-Sachs’ lesions.

32.2.4 Ultrasound

Diagnostic ultrasound has become more frequently used in the clinic and can be extremely helpful when combined with physical examination of the shoulder. With appropriate training and practice, this is a reliable technique to image the cuff tendons or biceps tendon tears and swelling, bursal thickening, and calcification of the tendons. Another value with ultrasound is that the examination can be performed dynamically allowing the examiner to visualize the cuff during, for instance, isometric contraction, which could be helpful to reveal cuff tears. Notably, imaging and interpretation are dependent on both the examiner’s sonographic skills and experience and the equipment used.

32.3 Shoulder Screening/Objective Measures of the Healthy Shoulder

32.3.1 Strength Testing

Shoulder strength testing is not only of a diagnostic value in the injured player but should also play a role in shoulder injury prevention strategies, e.g. preseason assessment, and also as a criterion for return to throwing after shoulder injury. Strength testing of the shoulder can also serve as a way to measure and monitor the capacity of the shoulder during the season to capture any decreases in strength since shoulder weakness, especially external rotation, is associated with shoulder injuries in handball players [9, 20].

Shoulder strength, both isometric and eccentric, is preferably tested with a handheld dynamometer (HHD) [21, 22]. Using a HHD is a very field friendly and reliable way to measure shoulder strength, and several different test positions have been described in the literature, supine, prone, seated, or standing, with the shoulder in natural position or abducted to 90° (See Videos 32.7, 32.8 and 32.9). Regardless of the position of the player and the shoulder, the HHD is placed 2 cm proximal of the styloid process of the ulna. The player is instructed to push for 5 s, gradually increasing the force against the HHD up to their maximum. The test can either be performed as a strict isometric test, so-called make test. In this case, the examiner keeps the HHD as stable as possible, while the players push against it. In this case, a belt could be used to secure a stable position. It can also be performed as a "break test", which initially is the same as the "make test", but in the end of the contraction, the examiner will push the HHD and try to "break" the force that the player is creating. Notably, even though most of the shoulder strength measurement procedures have shown good reliability, the strength measured in these different positions varies. This must be considered when comparing results from tests where different measurement techniques have been used. Strength in each direction is of interest and also strength ratio between ER and IR as well as eccentric ER and isometric IR.

Fact Box
Several studies have shown a relationship between shoulder muscle weakness and shoulder injuries. HHD is a field-friendly, reliable, valid, and safe tool to measure shoulder strength in handball players. Shoulder strength can be part of a preseason assessment and also as a criterion for return to throwing after shoulder injury. Strength testing of the shoulder can also serve as a way to measure and monitor the capacity of the shoulder during the season to capture any decreases in strength.

32.3.2 Range of Motion Testing

Several methods have been described in the literature, and most of them show high reliability [21]. One common way to assess ROM is with the player in supine, with the shoulder abducted 90° and rotated 90°. In this position, the scapula is thoroughly stabilized by fixing the coracoid process and the scapula spine with one hand. The other hand rotates the player's arm in internal-external rotation, respectively, until the motion of the scapula is felt. In that position, the angle degrees are measured with an inclinometer or a smartphone with an inclinometer application or a goniometer aligned with the ulna; the latter requires two testers (see Figs. 32.21 and 32.22).

Fig. 32.21 Assessment of external rotation ROM

Fig. 32.22 Assessment of internal rotation ROM

This is a reliable way to measure passive ROM in the shoulder joint; however, a recent study have showed that the maximal ER measured as described above does not correlate with the external rotation angle during throwing [23]. As a certain muscle tension around the shoulder in handball players is required to manage the impressive force that occurs during throwing, this could probably explain the lack of correlation. Therefore, we also suggest a more thorough measure for ROM where IR is tested with the arm in 90° forward flexion and ER where both scapula and the humeral head could be fixated and assisted (see Video 32.10). However, this way to assess ROM is obviously more provocative for the shoulder and could be too provocative in the painful player.

32.3.3 Clinical Interpretation of Shoulder Range of Motion

Lately there has been a large focus on the concept of GIRD (glenohumeral internal rotation deficit) and its relation to shoulder injuries in throwers, and different definitions of GIRD have been presented. Regardless of cut-off values, GIRD is defined as loss of internal rotation in the dominant shoulder compared to the non-dominant to some extent. However, many overhead throwing athletes, handballers included, are exposed to frequent throwing during their adolescent growth period. This leads to adaptations of the shoulder in the form of a relative retro-torsion of the humerus and the therefore apparent reduction of internal rotation in the dominant shoulder compared to the non-dominant side (while apparently increasing the range of external rotation). Therefore, the total rotational range of motion, that is, the sum of internal and external rotation range, is better compared between sides for any individual. Where differences are present (increase or decrease), the side-to-side difference in humeral torsion needs to be measured to ascertain if the athlete requires more or less internal or external rotation range in comparison to their uninjured side. While humeral torsion can be measured with X-Ray, CT, and MRI, clinically it's valid and reliable to use diagnostic ultrasound, and the procedure takes only a few minutes [24] (see Video 32.11).

32.3.4 Additional Tests for Shoulder Function and Performance

In addition to the assessments described above, testing shoulder performance in a more handball-related context could be useful. However, these tests have not been fully evaluated in terms of risk factors for shoulder injuries, so findings from such tests must be interpreted with this in mind. Still, the results from such tests can serve as baseline values and be used as guidelines during rehab and return to sport as well as monitoring any changes during the season.

32.3.4.1 Upper Quarter Y-Balance Test

Weight-bearing shoulder function can be assessed using the upper quarter Y-balance test (see Fig. 32.23). This test puts a great demand on the shoulder regarding stability and interaction with the trunk, and the results from this test correlate with isokinetic shoulder and elbow strength [25].

32.3.4.2 Medicine Ball Throwing

Medicine ball throwing test can be done in several ways. The most commonly described tests are seated medicine throws, overhead throws, and backward throws. In the seated medicine ball test, the player is seated with the back against a wall. In this position, the player performs a chest throw with the medicine ball, and the distance is measured (see Fig. 32.24). These test correlates with throwing velocity, and a recent study found that training medicine ball throw of different types during a 6-week period increased the throwing velocity in handball players [26].

32.3.4.3 Throwing Analyses

Throwing velocity can easily be measured using a radar gun. Knowing the player's maximum throwing velocity can be helpful in several ways: as a return to throwing criteria, also in throwing

Fig. 32.23 Upper limb Y-Balance test

Fig. 32.24 Medicine ball throw

programmes during rehabilitation to have the player throw at a certain speed. Additionally, video recording of the player's throwing technique can be useful, particularly if one has video of the player when he or she is uninjured to detect any change in throwing motions. This can be done with two sets of cameras, one in frontal plane and one in sagittal plane. It's important to recall that this only gives a rough estimation of the kinematics and is not as accurate as motion analysis done with a more advanced motion system. However, larger changes, which perhaps could be more clinically relevant, could be detected.

32.3.4.4 Monitoring Throwing Load

Since throwing is a major part of handball and large increase in workload is associated with shoulder injuries, monitoring the throwing load could be of value. Several different ways have been described, from questionnaires to more advanced technique such as accelerometers. However, most of the research in this area is done in other throwing sports such as baseball and cricket, and the evidence of such monitoring in handball is sparse even though it looks promising [27, 28].

32.4 Take-Home Message

Shoulder injuries, and especially non-traumatic injuries, are common in handball, and therefore deep knowledge of the shoulder assessment as well as functional anatomy of the area is critical for diagnosis and to understand injury mechanisms, rehabilitation, and return to sport tests. Shoulder diagnosis should not be based on one or two tests alone, but rather a combination of a thorough history and a combination of tests, where the tests are chosen based on the history. The careful clinician will likely be able to infer a likely diagnosis from the combination of mechanism of injury and presenting symptoms in the majority of cases, and subsequently use the physical examination and imaging to confirm this.

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33

Rehabilitation of ACL Injury in the Handball Player

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33.1 Epidemiology of ACL injury

ACL injuries occur at a rate of approximately 70–80 injuries/100,000 people per year in the general population [1, 2]. In sporting populations, the incidence of ACL injury is as high as 500–8500/100,000 athletes per year in team ball sports [3]. Handball is the fourth most common cause of ACL injury and reconstruction in Sweden, accounting for 6% of all patients [4].

33.1.1 Acute Knee Injuries in Handball

Knee injuries are common in handball, comprising 11–15% of all acute injuries in adult elite male and female players [5–8]. In young handball players, acute knee injuries are even more prevalent, representing 15–28% of all acute injuries [8, 9].

Every year, 1–4% of handball players sustain an ACL injury [6, 10–12], with slightly higher incidences in adult players compared to youth players. A top-level female team can expect an ACL injury each season, while teams at the sub-elite level can expect an injury approximately every other season [13]. These numbers are comparable to the injury incidence in female football [14].

33.1.2 Primary Prevention

Prevention programmes are typically directed towards teaching proper technique, e.g. during plant and cuts and landings—the two main injury mechanisms in elite female handball

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players [15], and improving strength and neuromuscular function of the lower extremity and trunk. Targeted injury prevention programmes can reduce the annual incidence of ACL injuries in handball by 30–70% [10, 16]. Therefore, these programmes should be offered to all handball players, irrespective of their level of play.

33.2 Management of ACL Injury in the Handball Player

Handball players with ACL injury have two possible treatment options:

1. High-quality prehabilitation *plus* ACL reconstruction *plus* high-quality post-operative rehabilitation
2. High-quality rehabilitation alone (non-surgical treatment of the injured ACL) *plus* the option for delayed ACL reconstruction

Non-surgical treatment may be chosen in combination with activity modification, as a short-term treatment option (e.g. to finish the season before having ACL reconstruction) or as a definitive management option in players who do not wish to return to playing pivoting sports (including handball) or do not have dynamic knee instability in pivoting sport. Irrespective of the treatment option the player chooses, high-quality rehabilitation is required.

Prehabilitation (treatment aimed at addressing impairments in the acutely injured knee) should always be completed prior to ACL reconstruction. The main goals of prehabilitation are no knee effusion, full knee range of motion and symmetrical quadriceps strength (within 90% of the uninjured side). Achieving these goals is prognostic of superior functional outcome following ACL reconstruction, and these benefits are sustained up to 2 years after surgery [17].

Combined injuries to the ACL and other knee joint structures (e.g. meniscus) may be more common in handball compared to other sports [18] and may be an appropriate indication for surgical treatment—meniscus repair may help to preserve joint health.

33.3 Rehabilitation After ACL Injury in the Handball Player

Handball players with ACL injury (whether treated surgically or non-surgically) must complete a high-quality, supervised, criterion-based rehabilitation programme with high adherence. This chapter provides guidance on how to structure a high-quality rehabilitation programme for the handball player with ACL injury, whether this is after surgical or non-surgical treatment. Rehabilitation principles should be followed irrespective of whether the player wants to return to handball or modify participation in sports.

The overarching goal of rehabilitation is to restore knee function so that the athlete can participate fully in all aspects of life with an acceptable risk for reinjury and post-traumatic osteoarthritis. For the handball player, this often translates to safe participation at the preinjury level (or higher) of handball. However, there may be appropriate reasons for the modification of handball participation, and the player's goals may change over the course of rehabilitation. The key is that individualised rehabilitation is responsive to these changes.

33.3.1 Rehabilitation Content

Regular assessment with feedback provided to the player ensures that rehabilitation is appropriate for his or her current functional level and targets relevant impairments. Three common impairments have important implications for knee function and post-traumatic osteoarthritis and should be afforded special attention:

1. Loss of knee extension range of motion [19]
2. Quadriceps strength deficits [20, 21]
3. Aberrant biomechanics, characterised by knee stiffening, dynamic valgus and knee unloading [22–24]

Rehabilitation must be tailored to the specific skill demands of playing position while also incorporating focus on general performance characteristics of acceleration, agility, co-ordination, balance, jumping, reaching and endurance. Therefore, specific knowledge of handball is an advantage—clinicians should also engage with coaches when planning rehabilitation programmes to discuss aspects related to technical and positional demands.

Rehabilitation for the handball player must incorporate exercises that train neuromuscular function specific to cutting, pivoting, turning, jumping and landing (Table 33.2) because they are vital movement patterns for successful handball performance. These are also movements with increased risk for ACL injury. The specific demands of handball mean that exercises aimed at training cutting and pivoting should be progressed to prepare the player for offensive actions or taking a shot. Exercises aimed at training landing technique should prepare the player for landing after a jump shot or making a block. Perturbation training may be appropriate since, in the game situation, these movements are often performed while the player receives contact.

Psychological factors such as motivation, reinjury anxiety and athletic confidence play an important role during rehabilitation and return to play, which may be related to reinjury risk upon return to play and should be addressed during rehabilitation [25]. Goal setting and consistent assessment and feedback are simple approaches that can easily be incorporated into any rehabilitation programme to build confidence and self-efficacy for playing handball.

33.3.2 Exercise Progression

Rehabilitation progression is based on the player meeting clinical milestones that follow tissue-healing timeframes. Regular assessment of effusion and pain is essential to adjust the overall load in rehabilitation and everyday life. This facilitates optimum response to exercises while minimising the risk of injury to the healing tissue (optimal loading). The principles for progression are similar with a surgical and non-surgical approach, but a slower rate of progression should be expected following surgery. The graft type used for ACL reconstruction, and associated injury or surgery to other ligaments, menisci or articular cartilage, may require specific adjustments to the rehabilitation programme.

A sound clinical reasoning framework for exercise progression is essential for successful rehabilitation. Blanchard and Glasgow [26] propose a stepped approach to progression that can be applied to any exercise. The exercise starts with an internal focus (i.e. the focus is on the exercise, rather than contending with other external factors). The exercise is progressed by changing characteristics such as duration, speed, distance and repetitions—gradually building in external factors (e.g. perturbations or changes in surface). Throughout this process, the progressions should be harmonised with effective goal setting.

The timeline for healing of the ACL graft following reconstruction surgery is still unclear in humans, although animal models suggest that the graft is unlikely to reach full biomechanical potential until at least 9 months following surgery [27]. Although there are fewer data from humans, it is unlikely that the graft maturation process would be shorter in humans [28]. This biological fact has important implications for decision-making in rehabilitation, since it provides a strong argument for introducing a minimum time before the player is cleared to return to handball (or other pivoting sports). Tissues take time to heal and recover full capacity to tolerate load. In addition, athletes can take more than 2 years to recover preinjury neuromuscular function following ACL injury [27].

Handball players require a high level of neuromuscular function to cope with the demands of the sport and, if the player has had surgery, an ACL graft that is capable of withstanding the physical demands of the sport. The risk for subsequent knee injury can be substantially reduced if the player does not return to sport before 9 months following ACL reconstruction [20]. Young athletes (up to 25 years) have a notably high risk for new ACL injury [29]. Returning to pivoting sports is also a strong risk factor for new ACL injury [29], but the risk is markedly lower for players who are fully rehabilitated before they return [20, 30]. Therefore, it seems prudent to be particularly conservative with the young handball player and plan for return to handball at least 12 months following the index ACL injury or reconstruction. A similar approach may also be prudent with the adult player, but contextual factors (e.g. financial pressure to play handball) may also need to be considered.

Fact Box
Commence rehabilitation as soon as possible following ACL injury to:
Ensure optimal loading and facilitate tissue recovery.
Build/maintain confidence and motivation.
Provide the best opportunity for outstanding outcomes.

33.3.3 Rehabilitation Phases

There are five key phases in rehabilitation, each building on functional gains made in the previous phase. Progression from one phase to the next is made when the player meets specific criteria and not solely on a priori-decided time intervals with no reference to expected biological healing times. A physical conditioning programme should also be instituted in parallel with these rehabilitation phases (with modifications made as necessary to accommodate the healing tissues), aimed at training the physical performance characteristics (e.g. aerobic fitness, upper body strength and power) required for handball.

1. Prehabilitation (for players who choose ACL reconstruction)

Main Goals
- No knee joint effusion
- Full active and passive knee range of motion
- Ninety percent quadriceps strength symmetry

Preoperative loss of knee extension and quadriceps strength should be targeted as they are associated with poorer postsurgical outcomes [31].

2. Acute Phase (for players who choose ACL reconstruction or non-surgical treatment)

Main Goals
- No knee joint effusion
- Full active and passive knee range of motion
- Straight leg raise without lag

Treatments targeting knee extension range of motion and quadriceps function should commence immediately after injury or reconstruction surgery. Appropriate treatments include knee range of motion exercises, patellar mobilisation, neuromuscular electrical stimulation and gait retraining to achieve normal loading and reduce knee-stiffening patterns [31].

3. Intermediate Phase (for players who choose ACL reconstruction or non-surgical treatment)

Main Goals
- Control of terminal knee extension in weight-bearing positions
- Eighty percent quadriceps muscle strength symmetry
- Dynamic knee stability

Strength training begins with an adjustment period and progresses to heavy loads with few repetitions [32]. For dynamic knee stability, neuromuscular training should progress with gradually increasing difficulty (e.g. by introducing perturbations or unstable surfaces, Fig. 33.1). Movement retraining should focus on avoiding knee-stiffening strategies, optimising knee loading and controlling of dynamic knee valgus patterns to ensure that the player can maintain knee joint stability under rapidly changing loads during activity [33] without an increase in symptoms.

4. Late Phase (for players who choose ACL reconstruction or non-surgical treatment)

Main Goals
- Symmetrical quadriceps and hamstrings strength (>90% of uninjured limb).
- Symmetrical dynamic knee stability.
- Maintain (or build) athletic confidence.
- Progress sport-specific skills from closed skills with internal focus to open skills with external focus.

This phase should be individualised based on the specific athletic demands of the player. Generally, rehabilitation should include a combination of

Fig. 33.1 Perturbations can be introduced to neuromuscular training using a roller board. The task may be progressed from static standing on the roller board, to throwing and catching a ball while standing on the roller board. An assistant can help with this, or the player may throw the ball against a wall

impairment-specific heavy strength training (Fig. 33.2), power and agility drills (jumping, hopping, running) and handball-specific exercises. Preseason screening data (e.g. isokinetic strength, countermovement jump) can provide a preinjury baseline comparison and should be used in addition to comparisons to the contralateral limb (i.e. limb symmetry index). Progression from closed to open skills emphasises reactive elements of handball-specific skills (e.g. reacting and adjusting movement patterns to opposing player actions). Towards the end of this phase, participation in regular handball practice is gradually increased. There is a staged progression from modified training (participation in non-contact drills only) to full training (no restrictions on contact) to restricted match play (number of minutes) to unrestricted match play.

5. Injury Prevention Phase (for players who choose ACL reconstruction or non-surgical treatment)

Main Goals

- Maintain muscle strength and dynamic knee stability.
- Manage workload.

As the player fully returns to handball, an injury prevention programme should be performed at least twice per week as part of the normal team

Fig. 33.2 A leg press (single or double leg) exercise can form part of a heavy strength training programme for a handball player

training. Appropriate management of workload is also needed to reduce the risk for new injuries to other structures [34] and reinjury to the knee.

Fact Box

Key ingredients for successful ACL injury rehabilitation:

Start as soon as possible after injury.

Establish realistic expectations and motivation.

Focus on individualised, criterion-based progressions.

Respect biology and the timeframes for tissue healing.

High-quality content: safely challenge functional capacity, provide regular feedback and assessments and consider the specific demands of handball.

33.3.4 Discharge Tests for Return to Handball

There are five key recommendations for discharge tests for return to play [35] (Table 33.1). The sport-specific examples provided are not intended as absolutes—the clinician must make decisions based on the requirements of the individual player and available equipment and space (Fig. 33.3). Many tests are adequately interpreted as limb symmetry indices; the clinician may also have preinjury baseline data, or normative data from an athletic population, to compare to. Consistent assessments of symptoms must complement these assessments. Assessing movement quality—ideally using video (frontal and sagittal views)—is also a useful addition, both from a performance assessment and player feedback perspective.

Table 33.1 Suggestions for discharge tests for return to handball

Recommendation	Handball-specific example	Rationale
1. Battery of functional tests (players must pass all tests in a battery before return to play)	• Hop test battery • Running t test (agility) • Quadriceps strength	These are key functional criteria included in test batteries that have discriminant validity for ACL reinjury [20, 30]
2. Assess reactive elements of sports performance	Unplanned cutting task: player runs towards the assessor and assessor indicates with a hand signal whether the player should change direction to the left or right. The player reacts and makes the appropriate direction change as quickly as possible	Safe cutting movements are important for performance in handball. These are also movement situations where the ACL is at increased risk for injury. Training safe performance of cutting movements is important for performance and injury prevention
3. Incorporate decision-making steps that players use in real sport situations	Progress the previous unplanned cutting task example by constructing the task so that the player must react to another player/opponent instead of a hand signal from the assessor	Gradually building the complexity of the task within the team training environment enhances safety and sport specificity. For adequate performance in handball, players must be able to react to the movement of defensive players by making cutting movements
4. Monitor workload	• Rating of perceived exertion (RPE) • RPE combined with exposure (minutes)	Gradually increase workload to match the demands of the player. Combining a subjective workload measure with exposure (i.e. training minutes) provides a standardised measurement of internal and external workload that can be monitored over time
5. Assess psychological response	ACL—Return to Sport after Injury scale [36]	This is a condition-specific scale with evidence of discriminative validity for return to the preinjury sport following ACL reconstruction

Fig. 33.3 Various hop tests may be included as part of a battery of return to play tests for the handball player

33.4 Return to Play

Given that the goal of most injured handball players is to return to play, it is vital that planning for the return to play commences as early as possible during rehabilitation [35]. A flexible return to play plan, underpinned by SMART (specific, measureable, achievable, realistic, time limited) goal setting that is informed by consistent assessment and testing, will give the best chance for success [35]. The return to play plan may need to be re-evaluated during rehabilitation because it is not uncommon for the players' goals regarding sports participation to change during rehabilitation.

Return to play should be conceptualised as a continuum, not simply a milestone that occurs at the end of a rehabilitation programme [35]. The three elements of return to play following ACL injury in handball are:

- Return to participation: the period of recovery and rehabilitation following injury.
- Return to sport: the player is training (either modified training or full team training) but is not yet available for match selection.
- Return to performance: the player is selected to play matches and has reached his/her (and possibly the coach's) performance goals.

33.4.1 Return to Play After ACL Injury

Following ACL reconstruction, approximately two-thirds of athletes from a variety of sports return to their preinjury sport, and only half return to competitive sport [37]. The return to play rate is higher at the elite level—four out of every five athletes return to their preinjury level of competitive sport [38].

There are fewer data available regarding return to play rates following non-surgical treatment for ACL injury, although the highest quality data suggest that return to play rates are similar in young, active (nonelite) people who played contact and non-contact pivoting sports prior to ACL injury (Tegner Activity Scale levels 7–9) irrespective of whether they had ACL reconstruction or non-surgical treatment [39, 40].

33.4.2 Return to Handball After ACL Injury

Data regarding sustained sports participation and risk for reinjury in surgically and non-surgically treated handball players are sparse. Among elite male and female players in Norway, at least 60% returned to their preinjury level of handball [41]. There was a higher rate of return to the preinjury level among players who had non-surgical treatment of their ACL injury (82%) compared to those who had ACL surgery (either repair or reconstruction (58%)). However, these results should be interpreted cautiously since the numbers are small, and in some of the athletes included in the study, the surgical and rehabilitation approach is unlikely to reflect contemporary practice [41].

In a more recent pair-matched study, 55% of non-surgically and 62% of surgically treated (ACL reconstruction) sub-elite level I pivoting sports athletes returned to sport after 1 year. Although the most common sport in this sample was football, 29% of these level I athletes played handball, and the rate of return was similar between sports [42].

Among recreational players in Sweden, 38% returned to their preinjury level of handball following ACL reconstruction [43]. While handball players comprised only 5% of the study population, the rate of return to handball was similar to the rate of return to other team ball sports (football and floorball) [43].

33.4.3 Factors That Influence Return to Play Following ACL Injury

Young age, male sex, playing elite level sport and being psychologically ready to return to play are prognostic factors for return to play following ACL reconstruction [37]. The primary reason for non-return to play after ACL injury is anxiety about sustaining a new injury [44]. Psychological factors (confidence and fear of reinjury) are strongly associated with returning to the preinjury sport [37], whereas physical function is only weakly related to returning to play.

Given that psychological factors are potentially modifiable, it may be important that these factors are adequately addressed during rehabilitation. Early identification of players with low confidence and high fear of reinjury may be possible using the ACL-Return to Sport after Injury scale [45]. This may facilitate the timely introduction of strategies aimed at improving psychological readiness to return to play in players for whom the goal is to return.

33.5 Reinjury Prevention

Avoiding subsequent ACL injury, either to the same knee (e.g. graft rupture or meniscal injury) or to the contralateral knee, is a major challenge for players who return to handball after ACL injury. Approximately one in four young athletes who return to cutting and pivoting sports after ACL reconstruction will sustain a subsequent ACL injury, often early after returning to play [29]. Players who return to play after ACL injury are also at increased risk for other knee injuries. Elite players who returned to football after ACL reconstruction had a fourfold risk for new acute knee injury and overuse injury (e.g. synovitis, tendinopathies) compared to previously uninjured peers [46].

Modifiable risk factors that may increase the risk of subsequent ACL injury include movement asymmetries and remaining deficits in biomechanics and neuromuscular control [22]. It is unclear whether these asymmetries and neuromuscular control deficits exist prior to the first ACL injury or if the player develops compensatory mechanisms during rehabilitation or after returning to play. Regardless, it is imperative that the handball player who returns to play after ACL injury continues with a neuromuscular training

Fig. 33.4 Handball player performing a balance exercise as part of an ACL injury prevention programme

Table 33.2 Knee injury prevention programmes for youth and adult handball players

Youth players [10]	Adult players [16]
Warm-up exercises (4 min) Jogging, backward running, sidesteps, sideways running, running with trunk rotation, running with stops and cuts, speed run *Technique (4 min)* Planting and cutting movements, jump shot landings	*Floor exercises (5 min)* Wk1: running and planting Wk2: jumping/landing exercise Wk3: running, plant and cut with the ball Wk4: 2-leg jumping/landing with perturbations Wk5: running, plant and cut with jump shot and 2-legged landing
Balance (4 min) On a balance mat or wobble board (1- or 2-legged stance), pass the ball, squats, bounce with the ball, push an opponent off balance	*Balance mat exercises (5 min)* Wk1: 1-legged, pass the ball Wk2: jump shot from a box with 2-legged landing Wk3: step down from box with 1-legged landing Wk4: stand on the mat; push opponent Wk5: jump and turn on the mat
Strength and power (3 × 10 reps) 1 quadriceps exercise; squats, bounding strides, forward jumps, jump shot with two-legged landing 1 hamstring exercise; Nordic hamstring lowers	*Wobble board exercises (5 min)* Wk1: 2-legged; pass the ball Wk2: 2 and 1-legged squats Wk3: 1-legged; pass the ball Wk4: 1-legged; bounce the ball Wk5: stand on the board; push opponent

Programmes performed as part of the warm-up before handball practice 2–3 times per week during preseason and then 1–2 times per week during the in season

programme (Fig. 33.4, Table 33.2) as a part of the normal training routine throughout his or her active career. This programme should be performed by all players in the team.

Monitoring and adapting the player's workload throughout rehabilitation are important to prevent reinjury and improve performance. This is particularly relevant when the player is gradually introduced to team training (late- and injury prevention phases of rehabilitation) and at return to full training. For ACL injury, running, cutting and jumping loads are probably of particular relevance. To reduce the risk for subsequent injury, the player should reach a sufficient overall level of fitness by completing a progressive optimal loading programme before he/she returns to unrestricted team training and matches.

Running workload may be monitored by evaluating both external load (e.g. total distance and amount of high-intensity running) and internal load (e.g. RPE). Especially, avoiding large peaks in the acute-chronic workload ratio (acute referring to the workload in the current week and chronic to the average workload in the last 4 weeks) may have an injury prophylactic effect [47]. Accurately measuring workload, accurately analysing and interpreting the data and effectively incorporating these data into clinical practice throughout rehabilitation, return to training and competition and return to performance are central components of safe return to play. If any of these steps are inadequately managed, the data are meaningless.

33.6 Take-Home Message

Rehabilitation for the handball player with ACL injury should commence as soon as possible following the injury to ensure optimal loading and facilitate tissue healing, to build the player's confidence and motivation and to provide the best opportunity for the player to reach his or her sports participation goals. Individualised rehabilitation that emphasises the physical performance characteristics needed for successful handball performance must incorporate criterion-based progressions that also respect the time required for biological healing.

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34

A Biomechanical Perspective on Rehabilitation of ACL Injuries in Handball

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Team handball is one of the highest demanding sports with regard to requirements of rapid cutting deceleration of cutting, pivoting and jump-landing movements. It is a sport with high knee mechanical constraints, and therefore the most serious injuries reported in handball are knee injuries (7–27%), ACL injury accounting to 50% of all ligamentous knee injuries [1, 2].The desire of an athlete to return to sport (RTS) after anterior cruciate ligament (ACL) injury is a major indication for ACL reconstruction (ACLR) surgery. At the same time, often, the most important outcome for the athlete, and regardless the level of play, is the capability to return to sport [3, 4]. However, recent systematic reviews and meta-analyses report that 65% of the patients will return to their preinjury level of sport after ACLR and about half of them after revision [5]. Various types of grafts are used for ACLR and revision surgery. Hamstrings tendons (HT) (usually semitendinosus and gracilis as a four-strand graft) and the patellar tendon (harvested as a bone-patellar tendon-bone (BPTB) are, by far, the most common autografts used. More recently the suitability of the extra-articular graft augmentation for rotational stability restoration in ACL reconstructive surgery has also been discussed. Looking into the best available evidence, it seems that there is no real consensus about the superiority of BPTB or HT grafts for ACLR when treating high-demand athletes. We believe that the graft choice decision in handball, as in other sports, should be multifactorial taking into account the type of player (outside, inside playing position, knee anatomical features), age, associated intra-articular knee injuries, rotational stability, preoperative kinematics and expectancy to return to previous competitive level.

The biomechanical aspect of the ACL rehabilitation procedure has been highlighted during the latest years, due to its intrinsic relationship with proper graft-healing promotion [6–8]. Indeed, the relevance of an adequate motor skills regaining process in order to maximize muscle function and optimize acting net joint moments

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as well as the neuromuscular coordination in order to manage the ground reaction force resultant vector properly has been put in the spotlight recently [9–11]. These factors aim to enable the athlete to maximize his/her performance after injury, while minimizing the re-injury risk.

Regarding ACL injury rehabilitation, many research issues have been addressed during the last years, ranging from the inferior age limit for ACL reconstruction, the importance of prehabilitation on successful outcomes after repair, the clinical prediction rules for ACLR or conservative management, to the importance of an objective criteria-based rehabilitation progression vs. a rehabilitation protocol [12, 13].

As widely reported, Olsen et al. [14] described the so called position of no return for ACL injuries in handball, being a triplanar motion including increased tibial rotation, femur adduction and internal rotation and a frontal plane knee valgus collapse. Several years later, Quatman et al. [15] corroborated this issue demonstrating significant increases on ACL loading (in vitro) when combining a medial knee joint opening, a rotation and an anterior shear pull. Many investigations have been carried out at the same time trying to elucidate which muscles would prevent knee joint triaxial valgus collapse to a greater extent, in order to design the most effective strategy for both ACL injury prevention and rehabilitation. In this context, ACL injury prevention programmes in handball have targeted several biomechanical (such as knee abduction moment (KAM) and angular excursion reduction) and physiological (semitendinosus to vastus lateralis muscles activation ratio promotion) adaptations that are supposed to contribute to the reduction of the onset of this injury. As it would be explained more in detail through this chapter, it would be important to both sport scientists and athletic trainers and coaches to highlight the importance of landing technique in the management of the ground reaction forces in order to reduce excessive soft tissue stress at the knee level and, hence, this joint injury risk. Thus, it seems that ACL injury prevention programmes in handball targeting this issue need to be implemented in order educate players with better (and safer) landing strategies.

34.1 Jumping Biomechanics Evaluation in Handball: A Historical Perspective and New Trends

Vertical jumping performance is considered a key component of many training routines in numerous sport disciplines and conditioning programmes [16–18]. For instance, it has a direct relationship with several explosive activities such as jumping and sprinting [19]. Moreover, in the last 30 years, other athletic tasks such as plyometric exercises have also been studied and implemented by athletic coaches to maximize the performance of explosive activities [20]. The main goal of these studies has been to clarify several concerns related to adaptations of the human body to exercise and to describe basic movement patterns [20, 21]. To do so, direct mechanics-based procedures have been utilized to estimate the centre of mass displacement and to detail the biomechanics of jumping [19, 21].

On the other hand, it is well known that an incomplete or deficient rehabilitation programme after an ACL injury may increase the risks of both re-injury and ACL injury in the contralateral unaffected knee [22]. Thus, the identification and assessment of functional, biomechanical and neuromuscular deficits when discharging athletes with a previously reconstructed ACL from rehabilitation appear to be crucial for preventing ACL re-injury [23].

However, many other methods and instrumentations have recently been developed to evaluate vertical jumps [24]. Briefly, some such as optical cells and contact mats have been developed to assess jumping performance in terms of the jumping time duration [25, 26]. Others, through the description of force and/or vertical velocity by time curves, have estimated the centre of mass movement in humans [27, 28]. To describe the direct or inverse mechanics-based biomechanics of vertical jumping manoeuvres, force plates have become the gold standard during the last decades [29]. As such, numerous research articles related to vertical jumping-related biomechanics focused on both performance enhancement [17, 30, 31] and injury prevention and rehabilitation [7, 32, 33] have been published. Myer et al. (2014) reported an exhaustive biomechanical screening for ACL injury risk identification based on the knee abduction moment (KAM) magnitude. Authors reported that peak knee joint extension moment, peak knee abduction angle, an increased BMI and tibia length accounted for 78% of KAM during bilateral drop landing. The same author [34] recommended, in relation to the functional evaluations after ACL reconstructions, the utilization of unilateral functional jump tests after to examine the deficits between extremities among collegiate recreational athletes. It seems that unilateral actions allow the identification of residual jumping impairments related to a previous injury [35].

However, the equipment needed to perform the abovementioned studies requires a considerable financial investment and implies the necessity for highly trained staff that are familiarized with such laboratory-derived procedures. For many rehabilitation centres, this is not feasible. Recently, the latest advances in microelectromechanical systems have turned inertial sensor units (IUs) into a powerful tool for sports motion analysis related to both performance-related [24, 36] and injury rehabilitation and prevention-related fields [35, 37]. One of the main advantages in comparison to force plate-based procedures could be that IUs enable nonconditioned foot landing, thereby making functional and unplanned movement analyses possible at the laboratory environment or at the training field itself [38] (Fig. 34.1).

In relation to handball and biomechanical screenings for ACL injury risk determination, Kristianslund and colleagues [39] demonstrated that technique explained more than 60% of the variance encountered on KAM. Several technical aspects were addressed, such as cut width, knee valgus angulations, approaching speed and cutting angle. Also, in a biomechanical investigation of joint loading during side cutting in elite female handball players, Bencke et al. (2013) found external moments of outward rotation, valgus and flexion affecting the knee and external inward rotating moments affecting the hip. The authors highlighted the importance of the medial hamstrings and hip external rotators for counteracting the imposed knee and hip loading during the analysed task. The importance of the medial hamstrings has also been demonstrated in a prospective study by Zebis et al. [40], and weak hip external rotators have also been found to increase knee injury risk in athletes in previous studies [41, 42]. More recently, Zebis et al. [43] found that vastus lateralis to semitendinosus activation ratios can be optimized through 12 weeks of evidence-based ACL prevention neuromuscular training programme on female soccer and handball adolescent players.

These data may imply that using biomechanical methods to obtain information about loading patterns and joint kinematics during jumping, landing and side cutting may direct ACL injury prevention routines as well as enhance ACL rehabilitation programmes.

34.2 Jumping Biomechanics in Handball Elite Female Athletes in Relation to ACL Injury

Due to the intrinsic need for abrupt changes in direction and unplanned action management in handball, as well as the high game intensity, anterior cruciate ligament (ACL) rupture is one of the most devastating injuries that handball players can suffer from [14]. Female athletes have a greater ACL injury risk than do their male counterparts during the same jumping and pivoting tasks [44]. This greater injury risk has been associated with existing neuromuscular, anatomical and hormonal differences between sexes [45]. Moreover, an incomplete or insufficient rehabilitation programme following an ACL injury may increase the risk of both re-injury and injury of the unaffected contralateral knee [22]. Thus, the identification of functional, biomechanical and neuromuscular deficits before discharging these patients from rehabilitation appears to be crucial for ACL re-injury prevention in this population (Table 34.1).

In relation to handball sport, Myklebust et al. [46] identified functional, strength and anterior-posterior

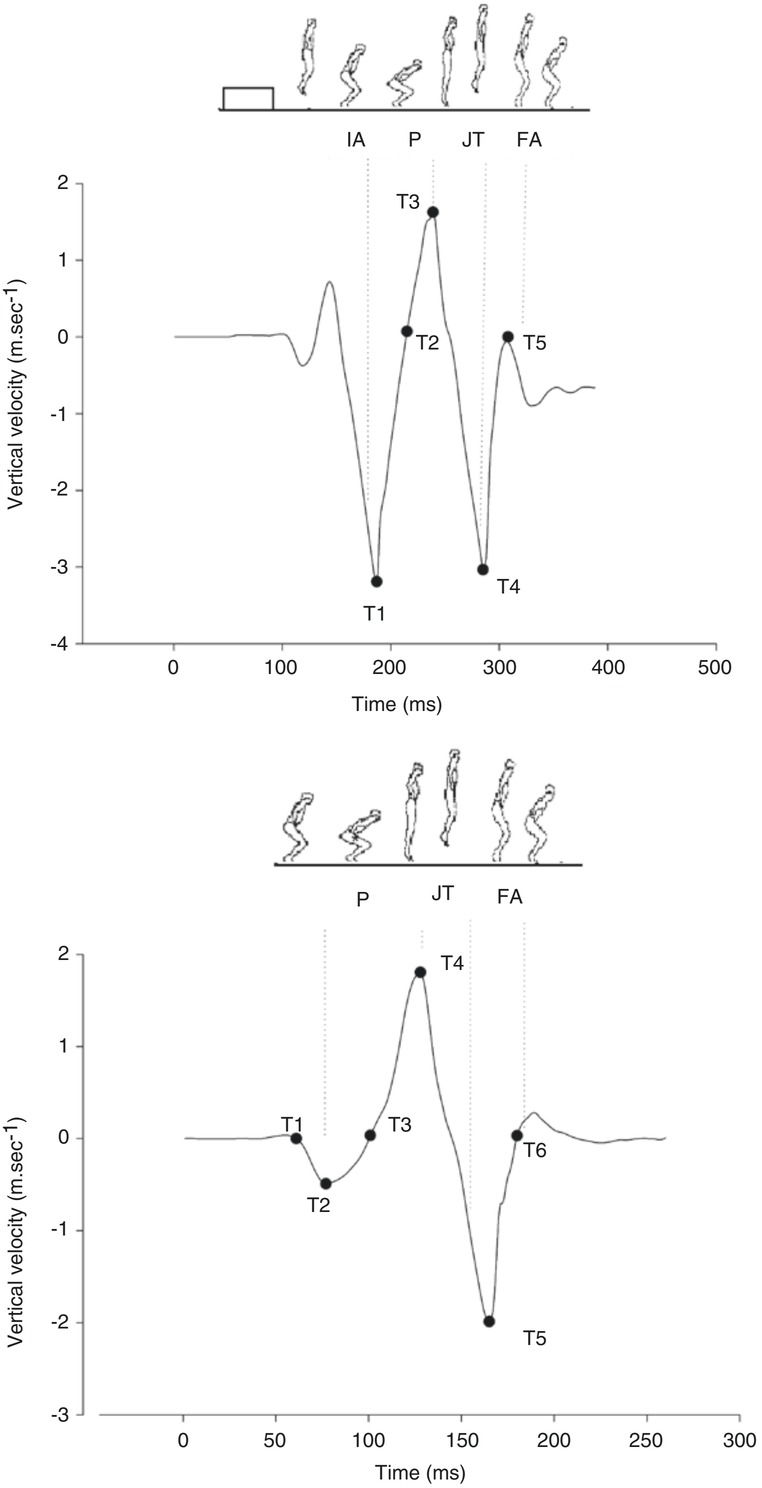

Fig. 34.1 *Z*-vertical axis force descriptive curves. Vertical bilateral drop jump explicative illustration (**a**). Vertical unilateral countermovement jump explicative illustration (**b**). IA, initial attenuation; P, propulsive phase; JT, jumping time; FA, final attenuation. Modified from vertical jumping biomechanical evaluation through the use of an inertial sensor-based technology. Modified from Setuain I et al. J Sports Sci. 2016;34(9):843-51. doi: 10.1080/02640414.2015.1075057. Epub 2015 Aug 10

Table 34.1 Relationship between mechanism, neuromuscular imbalance, and neuromuscular intervention for ACL injury prevention in female athletes [45]

Injury mechanism component	Underlying neuromuscular imbalance	Targeted neuromuscular intervention component
Knee adduction during landing	Ligament dominance	Improve landing technique
Low flexion angle in landing	Quadriceps dominance	Strengthen posterior chain
Asymmetrical landings	Leg dominance	Improve side/side symmetry
Inability to control centre of mass	Trunk dominance "core dysfunction"	Core stability and perturbation training

Adapted from Understanding and preventing ACL injuries: current biomechanical and epidemiologic considerations—update 2010. N Am J Sports Phys Ther 2010;5:234-251 [45]

knee joint laxity differences between both ACL injured and uninjured professional and recreational handball players in the long term since ACL injury event. It seems plausible that the available athlete's surrounding medical staff and material resources could vary depending on the level of competition in which the player is enrolled. This fact could affect injury rehabilitation and return to play outcomes.

Regarding biomechanical variables that could explain the higher ACL injury incidence observed among female athletes in handball, we should highlight the relevant contribution that knee abduction kinetics and kinematics play on the chance of this devastating injury to occur. In fact, as previously stated KAM displayed during a drop jumping task predicted ACL injury risk with 73% sensitivity and 78% specificity, and previously ACL injured athletes displayed 8° greater valgus angles than their healthy counterparts [7]. These, along with previous research demonstrating the significant correlation between trunk excessive motion and knee abduction load in both side stepping and jumping tasks [45], make this body region a very important mechanical segment to address when assessing ACL injury risk in relation to the sport of handball.

There have been many scientific debates regarding the long-term effects of sustaining an ACL injury. Some researchers have stated that sustaining an ACL injury leads to a 100% greater risk of osteoarthritis development [12]. Whether this increase on joint deterioration rate is due to the surgical procedure received, or due to abnormal lower-limb mechanics adopted from the time of reconstruction or even to native motor skills, is still a cornerstone for both sport clinicians and researchers.

In accordance with this, Setuain et al. [47] examined if biomechanical jumping differences persist among a cohort of elite female handball players with previous ACL reconstruction several years after return to top-level competition. In order to achieve this goal, an IU utilization-based simplified analysis was used. Results showed that previously, ACL-reconstructed elite female handball athletes may cope with persisting jumping biomechanics alterations (i.e. greater *X*-, *Y*- and/or *Z*-axis supporting accelerations and differing predefined jump phases' duration values) during the execution of the vertical bilateral drop jump (VBDJ) (Fig. 34.2).

Furthermore, this group of subjects showed altered angular excursion values around the (*X*-), (*Y*-) and/or (*Y*-) axes as well as an attenuated jumping capacity than their non-ACL-reconstructed counterparts during the execution of unilateral vertical drop (VUDJ) and countermovement (VUCMJ) jumps.

The magnified trunk-supported accelerations during jumping task executions have been shown to positively correlate with VGRF effects on the whole body produced at initial contact with the ground [48]. In this context, those reported by Setuain et al. [47] among the previously ACL-reconstructed subjects in the VBDJ may be explained by a previously reported trunk stiffening strategy [49] which could influence proper VGRF attenuation and kinetic energy reutilization through the countermovement phase of the manoeuvre affecting both joint resultant reaction forces and jumping performance. It has been previously reported that an excessively erected trunk position at landing can augment internal knee extension moment, resulting in greater ACL tensile stress when adding extra weight compared to a more flexed trunk position [49].

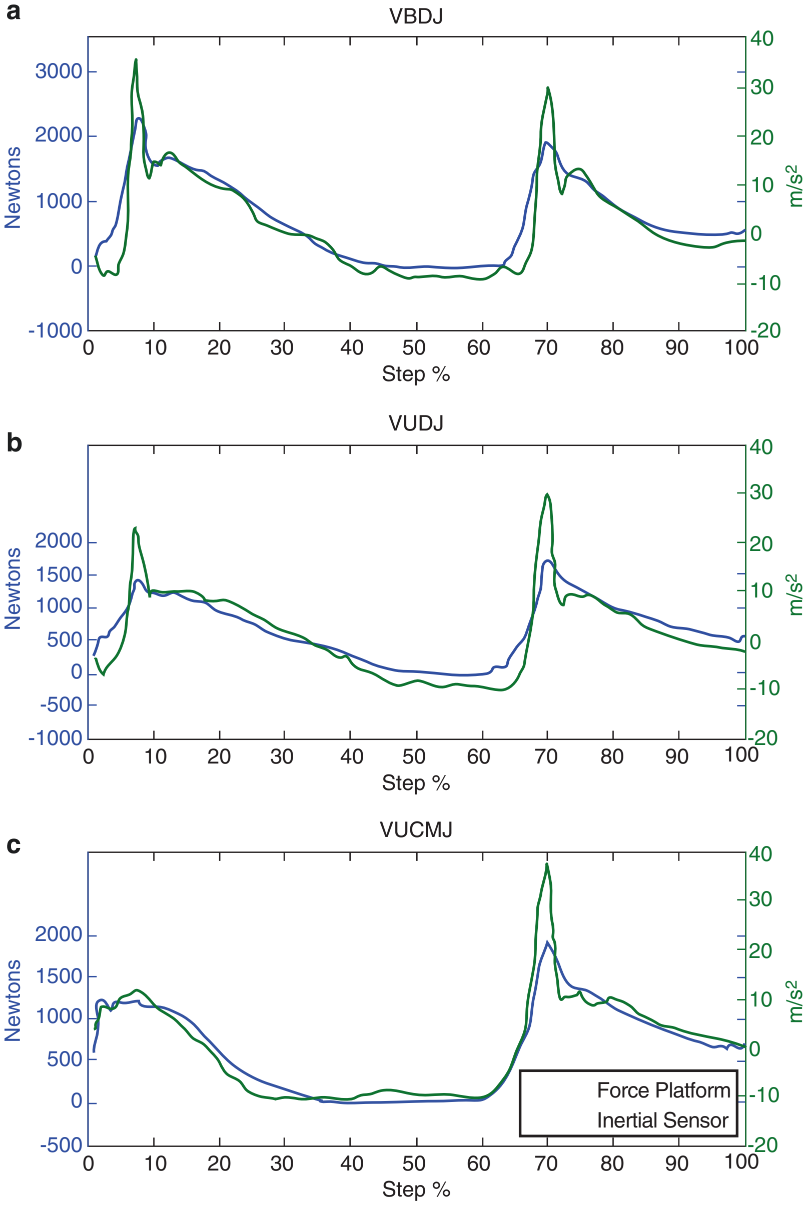

Fig. 34.2 Vertical force by time IU and force plate curves. Vertical bilateral drop jump (**a**). Vertical unilateral drop jump (**b**). Vertical unilateral counter movement jump (**c**). Modified from Setuain I et al. J Sports Sci. 2016;34(9):843-51. doi: 10.1080/02640414.2015.1075057. Epub 2015 Aug 10

It could be assumed that force production was compensated by the contralateral non-ACL-reconstructed leg in this bilateral task, leading to no differences in jump performance [9]. Furthermore, this fact may be explained by the elite profile of this study cohort in which exhaustive strength training routines are frequent.

With regard to unilateral tasks, the same authors [47] observed significantly ($p < 0.05$) lower trunk angular displacement excursions around the (*Y*-) and (*X*-) axes, among previously ACL-reconstructed athletes while executing a VUDJ. In these cases not the accelerations but the trunk displacements were shown to be decreased among ACL-reconstructed handball players. This fact could be explained by the more challenging demands with respect to balance and performance that the unilateral actions impose to the body, in order to maintain the centre of mass within the balance margins. In this sense, ACL-reconstructed athletes could have adapted their movement pattern through central motor control reprogramming during the unilateral jumping tasks into a more balance-ensuring action, thereby attenuating the imposed accelerations to the centre of mass limiting, in that way, the jumping performance [10, 33]. This fact could partially explain the observed jumping performance attenuation observed during the VUDJ and VUCMJ among both previously ACL-reconstructed players [50, 51]The sparse existing evidence regarding both short- and long-term biomechanical adaptations to ACL reconstruction among females handball athletes [46, 47] is a limitation and warrants caution when generalizing these results to younger or more recreational populations. Factors like type of reconstruction (graft type choice, primary vs. revision single vs. double bundle, extra-articular reinforcement), the kind of rehabilitation performed, and the time course from injury to surgical repair and to return to play, could be adequately controlled, in order to avoid bias when designing future investigations regarding this topic.

In summary, in view of the existing evidence, it seems that female handball professional players cope with several lasting biomechanical adaptations after ACL reconstruction, despite returning back to competition. This fact could indicate a sex-dependent prevalence of functional consequences to ACL reconstruction, keeping in mind that fully functional restoration is more prevalent among their male counterparts on basketball, soccer and handball [50–52]. Whether this jumping mechanics adaptations predispose them to a higher re-injury rate should be addressed in properly designed prospective follow-up studies.

In line with prevention studies showing a diminished knee flexion, an increased knee valgus torque and excursion along with increased trunk mediolateral accelerations, it seems that female athletes would benefit from prevention training routines targeting these issues. For example, plyometric training in order to minimize VGRF at landing [53] and core stability exercises to increase trunk motor control and stability, as well as specific exercises addressing the co-activation of medial hamstrings when performing selected athletic tasks, [43, 54] could be implemented in order to help decrease the ACL injury incidence in this sport population. In addition, technical training in relation to foot positioning during the planting phase for cutting manoeuvres should be also supervised during the training routines on the court especially in young handball players, due to its demonstrated relationship with high knee valgus overload [39].

34.3 Jumping Biomechanics in Handball Elite Male Athletes in Relation to ACL Injury

As stated in the previous heading, female athletes have a greater ACL injury risk than their male counterparts during the same jumping and pivoting tasks [44], which has been associated with neuromuscular, anatomical and hormonal differences between the sexes [45]. In contrast, evidence for neuromuscular or biomechanical risk factors for ACL injuries in male athletes appears to be mainly related to dysfunctions occurring at the trunk and hip joint levels [55]. However, in line with previous relevant research from Quatman et al., it should be kept in mind that many of the neuromuscular imbalances that make females more prone to ACL injury are also present among males albeit to a quite lesser extent [56]. Reduced hip range of motion, especially internal rotation, has also been found in male soccer players with previous ACL injuries [57].

As stated in the previous section, one of the clinical key points surrounding the ACL injury event is the long-term joint health status. In relation to this fact, it seems that a sex-dependent effect exists. In a large retrospective study on ACL-reconstructed athletes, handball activity seems to be associated with a greater risk of osteoarthritis but only for male handball players [58]. Male handball players were more susceptible to have cartilage lesions compared to other sports, while female handball players did not differ from other sports. Overall, males have more cartilage injuries than females.

Studies on long-term biomechanical discrepancies between ACL-reconstructed athletes and healthy, or inter-limb discrepancies, are sparse. Setuain et al. [51] evaluated 22 elite male (6 ACL-reconstructed and 16 uninjured control players) handball players a mean of 6 years after primary ACL reconstruction. The participants performed a vertical jump test battery that included a 50 cm vertical bilateral drop jump (VBDJ), a 20 cm vertical unilateral drop jump (VUDJ) and vertical unilateral countermovement jump (VUCMJ) manoeuvres using an IU. Elite male handball athletes with previous ACL reconstruction demonstrated a jumping biomechanical profile similar to control players, including similar jumping performance values in both bilateral and unilateral jumping manoeuvres, several years after ACL reconstruction. These findings correlate with previous research showing fully functional restoration of abilities in top-level male athletes after ACL reconstruction, rehabilitation and subsequent return to sport at the previous level. In agreement with the latest results, Buesfield et al. [50] showed non-significant differences in playing-related abilities among elite professional male basketball players, and Brophy et al. [52] demonstrated similar results in male soccer players. Thus, the restoration of full jumping capacity appears to be common among high-performance male athletes after ACL reconstruction. This fact, keeping in mind the previously observed lasting biomechanical jumping mechanics alterations among female elite handball athletes, could highlight a sex-dependent effect on functional outcome after ACL reconstruction which has been previously described in the literature [59] in a non-professional cohort of athletes.

Finally, in the authors' opinion, the existing ACL injury incidence discrepancies between genders should be considered, when targeting injury prevention. However, it still seems adequate to appropriately evaluate male handball athletes, looking for aberrant motor patterns as well as neuromuscular deficiencies in order to specifically intensify ACL prevention training among those males more prone to injury.

34.4 Summary and Future Perspectives

The present chapter has reviewed the biomechanical aspects of handball jumping, landing and side cutting performance in relation to ACL injury and has highlighted the key elements to address when preparing athletes for handball participation. Besides gender differences with regard to injury risk, biomechanical jumping performances exist, and recent studies also demonstrate that male players seem to recover to a greater extent in the long term, than female athletes. This also emphasizes the perspectives for future research, further understanding of why these gender differences persist and subsequently directing more attention to target these discrepancies during early and late rehabilitation after ACL injury. It also seems evident that utilizing biomechanical experimental methods in optimizing the evaluation of athletes returning to play may have a huge potential, both with existing and well-tested laboratory methods and with newer and more field-based approached like IUs. Future research is needed in this area.

Key Notes 1: Injury Incidence
Handball is a sport with high knee mechanical constraints, and therefore the most serious injuries reported in handball are knee injuries (7–27%); ACL injury accounts for around 50% of all ligamentous knee injuries. The desire of an athlete to return to sport (RTS) after anterior cruciate ligament (ACL) injury is a major indication for ACL reconstruction (ACLR) surgery.

Key Notes 2: Biomechanical Influence on Rehabilitation Outcomes

The biomechanical aspects of the ACL rehabilitation process have been highlighted during the latest years, due to its intrinsic relationship with proper graft-healing promotion. Indeed, the relevance of an adequate motor skill regaining process in order to maximize muscle function and optimize acting net joint moments, as well as the neuromuscular coordination in order to manage the ground reaction force resultant vector properly, has been put in the spotlight recently.

Key Notes 3: Triaxial Injury Mechanism

Triplanar knee motion includes increased tibial rotation, hip adduction and internal rotation and a frontal plane valgus collapse.

Understanding the components of injury mechanism and when it is reproduced during the game seems to be crucial in order to design the most effective strategy for both ACL injury prevention and rehabilitation.

Key Notes 4: Mechanical Contributors to Valgus Collapse

Peak knee joint extension moment, peak knee abduction angle, an increased BMI and tibia length, account for 78% of KAM during bilateral drop landing.

Jumping technique explained more than 60% of the variance encountered on KAM.

Authors highlighted the importance of the medial hamstrings and hip external rotators for counteracting the imposed knee and hip loading during the analysed task.

Key Notes 5: Relevant Information to the General Handball Sport Community

It would be important to both sport scientists and athletic trainers and coaches to highlight the importance of landing technique in the management of the ground reaction forces in order to reduce excessive soft tissue stress at the knee level, and hence, this joint injury risk.

Thus, it seems that ACL injury prevention programmes in handball targeting this issue need to be implemented in order educate players with better (and safer) landing strategies.

Key Notes 6: Sex-Dependent Outcomes After ACL Reconstruction

In view of the existing evidence, it seems that female handball professional players cope with several lasting biomechanical adaptations after ACL reconstruction, despite returning back to competition. This may indicate a sex-dependent prevalence of functional consequences to ACL reconstruction, keeping in mind that fully functional restoration is more prevalent among their male counterparts on basketball, soccer and handball.

Female athletes would benefit from prevention training routines targeting these issues.

Key Notes 7: Recommendation for an ACL Injury Prevention Programme Design

For example, plyometric training in order to minimize VGRF at landing and core stability exercises to increase trunk motor control and stability, as well as specific exercises addressing the co-activation of medial hamstrings when performing selected athletic task, could be implemented in order to help decrease the ACL injury incidence in this sport population.

In addition, technical training in relation to foot positioning during the planting phase for cutting manoeuvres should be also supervised during the training routines on the court especially in young handball players, due to its demonstrated relationship with high knee valgus overload.

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Rehabilitation of Acute Soft Tissue Injuries of the Foot and Ankle in the Handball Player

35

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35.1 Epidemiology of Foot and Ankle Injuries

Ankle injuries constitute one of the most common sport injuries. In a systematic review on ankle injury and ankle sprain, the ankle was the most frequent injury location in 24 of 70 included sports, with ankle sprain being the dominant ankle injury type [1]. Ankle sprains typically affect the lateral ligament complex (anterior talofibular, calcaneofibular and rarely posterior talofibular ligaments), comprising up to 90% of ankle sprains, and less commonly involve syndesmotic injuries and medial (deltoid) ligament injuries [2, 3]. Ankle sprains appear to be more frequent in females than in males, in children and in adolescents compared to adults and are most common in field sports and indoor/court sports, such as handball [1, 2].

An ankle sprain may negatively affect the athlete in several ways, including decreased performance, time lost from sports and adverse psychological effects. Absence from sports varies depending on several factors, including the grade of the injury (e.g. amount of ligament damage), location (e.g. syndesmotic injury or lateral ligament injury), use of tape or bracing upon return to sports and type of sporting demands. Less pain is often seen within the first 2 weeks after the injury, whilst enduring symptoms and decreased function may be present up to 1 year post-injury in more than one-third of patients [3, 4]. Prolonged symptoms and functional deficits are often seen with more complicated ankle injuries, e.g. with concomitant peroneus rupture or cartilage injury. Occurrences of re-injury and subjective instability are frequent, both being reported in about

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one-third of patients at 1-year follow-up. The risk of recurrent injury is twofold within the first year after the injury [3]. Long-term consequences of ankle sprain injury include development of chronic ankle instability (CAI), with residual symptoms of giving way and subjective instability present for more than 1 year after the initial sprain [2]. Prevalence of CAI in sporting populations, especially indoor/court sports, has been reported to be as high as or greater than 25% [3]. Further negative long-term consequences of ankle injury include accelerated onset of ankle joint osteoarthritis, decreased quality of life and reduced levels of physical activity [3].

Overuse injuries to the foot, such as plantar fasciitis, heel pad syndrome, tendinopathies of the midfoot (e.g. extensor tendinopathy, tibialis posterior tendinopathy) and various forefoot complaints such as neuromas, hallux valgus and stress fractures, are not uncommon in the general population and occur also among athletes. Some of the most common acute injuries include midfoot and metatarsophalangeal joint sprains, which may result in considerable absence from sports and long-term problems with degenerative changes that affect sports performance [5].

35.1.1 Foot and Ankle Injuries in Handball

Foot and ankle injuries are among the most common injuries in handball, comprising 20–23% of all acute injuries in adult elite handball players [6, 7], 14–21% of injuries in international tournaments [8, 9] and up to 35% of injuries in amateur players [10], with ankle sprain as the single most common injury type leading to time loss from play (Fig. 35.1). In young handball players, foot and ankle injuries account for a similar, or even higher, proportion of injuries, ranging between 25 and 32%, again with ankle sprain being the single most common acute injury [7, 11, 12].

Almost nine out of ten foot and ankle injuries have an acute onset [7] and in international tournaments commonly occurring as a result of player contact (65%) [8]. Regarding injury severity it has been reported from international tournaments that 25% of foot and ankle injuries were non-time-loss injuries, whilst 32% caused 1–2 days absence from training or matches, 21% up to 4 weeks absence and 7% more than 4 weeks [8].

Fact Box

Foot and ankle injuries are frequent in indoor/court sports, with ankle sprain being the single most acute injury in handball.

Most foot and ankle injuries are mild in nature, where the player is able to continue or resume training or match play within a few days; however about one-third of injuries cause absence more than 1 week.

High recurrence rates, residual symptoms and functional decrease are present in approximately one-third of athletes at 1-year follow-up after an ankle sprain injury.

35.2 Acute Management of Foot and Ankle Injuries

With an acute soft tissue injury to, e.g. ligaments of the foot and ankle, there is concomitant injury to blood vessels which results in bleeding and oedema at the injury site and adjacent areas. This in turn leads to pain, decreased range of motion and secondary hypoxic injury and reduced tissue healing. The initial management of acute soft tissue injuries therefore aims to reduce the initial bleeding and to minimize additional injury. The scientific evidence in terms of the effects of acute injury management is limited and mainly based on empirical knowledge [13, 14].

Acute management of soft tissue injury is similar for contusions, capsuloligamentous sprains and musculotendinous strains and has traditionally followed the acronym PRICE (protection, rest, ice, compression, elevation). To stress the importance of early mobilization to promote tissue healing, the acronym POLICE, exchanging rest with optimal loading, was recently proposed [15]. The principle is to cease the sport activity immediately after injury and to apply maximal compression over the injured site, e.g. with an elastic bandage.

Fig. 35.1 Acute ankle sprains are common in handball. Photo: Amanda Sigfridsson, Studio 11, with permission

Fig. 35.2 Acute management of an ankle injury using PRICE. Photo: Martin Asker, with permission

Ice treatment can also be applied in the acute phase, mainly as an analgesia but also to reduce tissue metabolism. The external compression stops capillary blood flow leading to ischemia, which causes pain after approximately 20–25 min, at which point the bandage is reapplied (with about 50% of full elasticity remaining). This milder compression should be continued up to 48–72 h after the injury at all times when standing and walking since the swelling can increase during this period. Ice treatment can also be continued over the first 48–72 h. It is recommended that the foot is elevated (at least 30 cm above the heart) when lying or sitting during the initial 48–72 h to further minimize swelling through the effects of gravity (Fig. 35.2).

In addition to the acute management, it is recommended that the athlete avoids heating (e.g. hot baths, sauna, heat packs), alcohol and massage during the first 72 h since this increases blood flow and may thereby increase post-injury swelling. The use of non-steroidal anti-inflammatory drugs (NSAIDs) in the management of acute soft tissue injury is controversial since these, in addition to an analgesic effect, also increase bleeding and reduce the inflammation that is part of the natural healing process. NSAIDs are sometimes recommended as part of initial management of ankle sprains to reduce pain and swelling and improve short-term function [16], but given their possible side effects, a restrictive use for acute soft tissue injuries, especially in the early phase after injury, is advocated [17].

Protection of the injured site in the acute phase is important in order to avoid additional injury and further bleeding. Movements that mimic the injury mechanism should be avoided. Movement restriction can be accomplished with an elastic strap or ankle brace and use of crutches. Reduced load and movement restriction may be used over the first few days after injury [14]. However, after that partial weight-bearing, mobilization and loading are important to facilitate tissue healing.

Cryotherapy after acute soft tissue injury of the ankle is used primarily for its analgetic effects. A skin temperature reduction to 13–15 °C, necessary for effective pain reduction, is normally accomplished within 5–10 min [14]. A cooling protocol with 10 min ice—10 min without—10 min cooling every second hour can provide efficient pain reduction with a low risk of adverse skin effects; it is recommended not to apply ice or cool packs directly to the skin, in order to prevent any adverse skin effects. The analgesic effect of cryotherapy is believed to be due to a reduced sensitivity and excitability of pain nociceptors in the skin, as well as reduced nerve conduction velocity, and reduced muscle spasm. In addition, pain may be reduced via the so-called gate control theory. Cryotherapy may also aid tissue healing by a resultant vasoconstriction, decreased permeability of tiny blood vessels and decreased cell metabolism, which could be favourable if there is an exaggerated inflammatory process at the injured site and nearby tissue (with resulting secondary cell damage). However, it may not be realistic to accomplish a temperature reduction down to 5–15 °C, which is needed to effectively slow down cell metabolism.

Fact Box: Acute Management of Soft Tissue Injuries of the Ankle

Stop sports activity immediately to **protect** the injury site.

Apply **compression** using an elastic bandage (full elasticity) as soon as possible to stop the bleeding. A focal compression pad can be used under the bandage over the injured site. Apply compression proximal to distal and about 15 cm above and below the injury site.

Use cryotherapy with **ice** or ice pack for pain reduction, approximately 20 min intermittently every 2 h. Continued use over the first 48–72 h.

Remove initial compression after 20–25 min and reapply compression using half the elasticity. Continued use over the first 48–72 h to control swelling is recommended.

Elevate the foot to reduce the effect of gravity. Continued use over the first 48–72 h to control swelling is recommended.

Unload the foot in the initial phase as needed, e.g. using an orthosis or crutches. After about 2–5 days, gradual **optimal loading** and weight-bearing are initiated to facilitate healing.

Heat packs, alcohol and massage should be avoided during the first 72 h as these may increase bleeding and oedema.

35.3 Rehabilitation After Acute Foot and Ankle Injury

Rehabilitation should be started directly after an acute soft tissue injury with the aim to support the healing process and gradually increase tissue capacity and load tolerance of the injured tissue, to regain function and to ensure as quick and safe return to play (RTP) as possible. The rehabilitation should also mitigate other negative consequences of the injury from a physiological and mechanical perspective (e.g. reduced load tolerance and tissue capacity as a result of decrease in physical activity, loss of cardiovascular fitness, reduced neuromuscular function) and psychosocial perspective (e.g. fear of movement, re-injury anxiety, low self-efficacy and social isolation).

35.3.1 Rehabilitation: General Principles

The rehabilitation should be individualized to the athlete, as the rehabilitation programme and goals depend on his or her demands, current life situation, function, the type and severity of the injury, the sporting demands, etc. A few general principles may be applied, however, where the rehabilitation follows different phases depending on the athlete's function and in conjunction with the stages of soft tissue healing. The time spent in each phase is variable, as are the criteria to progress to the next phase, and is based on symptom reduction and clinical signs (e.g. swelling, pain, joint laxity), gradual increase in function and an increased psychological readiness [18, 19]. Both within each rehabilitation phase, as well as between phases, a variation in prescription and progression of exercises (e.g. exercise duration, speed, distance, repetitions, intensity, etc.) is important in order to elicit the expected biological and neurological responses to the exercises [20].

35.3.1.1 Initial Phase

The initial rehabilitation phase concurs with the acute soft tissue healing phases after injury with inflammation, pain and loss of function. The primary goals are to protect the healing tissue, e.g. ligaments, reduce pain and swelling, regain joint range of motion and muscle flexibility and avoid muscle inhibition. Flexibility and range of motion exercises should start early whilst considering the tissue healing and limiting load at the injured site. Low-intensity cardiovascular training and strength endurance exercises, as well as lighter sport-specific exercises for non-injured parts of the body, may be included. Balance training, proprioception and stabilizing exercises are incorporated early in the rehabilitation. Criteria to progress to phase 2 is that rehabilitation exercises can be performed with no or minimal pain and clinical signs and with good muscle recruitment and activation.

35.3.1.2 Intermediate Phase

Phase 2 of the rehabilitation coincides with repair and remodelling of the healing tissue. Primary goals are to increase capacity and load tolerance of the injured tissue, whilst continuous protection is considered depending on the tensile strength of the tissue, and to regain good muscle function. Cardiovascular exercises and gradually increased intensity and dosage of endurance and strength training in the non-injured parts of the body are introduced, and gradually also involving the injured body part. Modified sport-specific exercises are continued. Criteria to progress to the next phase are avoidance of negative reactions to increased tissue loading, full joint range of motion and flexibility and partial restoration of muscle strength (e.g. 60% of the non-injured limb).

35.3.1.3 Late/Advanced Phase

Phase 3 corresponds with continued remodelling and maturation phases of the tissue healing, and the rehabilitation is progressed to become heavier and more intense. The primary goals include full restoration of muscular endurance and strength, cardiovascular capacity, neuromuscular control, balance and proprioception. High-intensity strength exercises and explosive strength exercises are introduced and gradually more sport-specific exercises including team drills and skills practice. Criteria to progress to the next phase are regained strength (e.g. >70–80% of the non-injured limb) and ability to perform sport-specific tasks with good neuromuscular control.

35.3.1.4 Return to Play

The last phase, RTP, concurs with continued maturity of the healing tissue. Exercises in this phase focus on sport-specific tasks and endurance and explosive strength exercises that resemble the specific demands of the sport. Controlled rehabilitation tasks performed with the same intensity as in full team training and match play should be completed before the athlete is allowed to return to team training. Primary goals are to regain full function at the same (or higher) level as before the injury, to regain high confidence and self-efficacy to perform the sport and to reduce the risk of exacerbation, re-injury or other subsequent injury at return to full training and matches.

35.3.2 Lateral Ligament Ankle Sprains

Standard care for grade I and II ankle sprains is exercise and ankle stabilization [21]. Similarly, for grade III total ligament tears functional training and bracing is also the initial treatment, although a period of immobilization for up to 10 days is normally recommended [16]. There is strong evidence for exercise therapy and bracing for the management of acute ankle sprain and prevention of recurrence [22], whilst there is also moderate evidence that neuromuscular training, e.g. static and dynamic balance, proprioception and strength, also has positive effects on functional outcomes in patients with chronic instability [23]. Surgery should be considered on an individual basis and only after a period of non-surgical management has failed, in patients with recurring symptoms [22, 24]. Currently there is insufficient evidence on the effectiveness of ultrasound, acupuncture and manual therapy to advocate their use in the treatment of ankle sprains.

Initial treatment of acute lateral ligament sprains of the ankle should follow the POLICE procedure described in Sect. 35.2. After minimizing initial bleeding and pain, the aim is to restore full range of motion (especially limited dorsiflexion is common after ankle sprains), muscle strength (especially peroneus musculature) and proprioception. The athlete starts with range of motion exercises in dorsiflexion and plantar flexion using movement without resistance and at high repetition. Inversion and eversion should be avoided initially but gradually introduced when pain and tenderness over the injured site diminish. The athlete should also commence isometric strengthening exercises in the acute phase to prevent muscular hypotrophy, initially targeting dorsal and plantar flexors.

Functional and sensorimotor deficits may be present several months after a lateral ligament sprain and should be targeted and evaluated during the rehabilitation [16]. It takes between 6 weeks and 3 months before ligament healing occurs after an ankle sprain, and a large proportion of patients have mechanical laxity and subjective instability at 6 weeks up to 1 year post-injury [25]. Hence, ligament healing is likely ongoing at the time of RTP after an ankle sprain injury for many handball players, and the use of an external support to avoid damage to the healing ligament and to mitigate recurrence risk is strongly advocated and allows for an earlier RTP. Restoration of neuromuscular control is also crucial to avoid re-injury. An example of an exercise rehabilitation programme after a grade I–II ankle sprain is shown in Table 35.1.

35.3.2.1 Range of Motion

Whilst fully off-loading the foot may be appropriate in the first 24 h after an ankle sprain, e.g. by using crutches, partial weight-bearing is then begun since early weight-bearing after a lateral ligament sprain helps reduce the swelling and maintain or increase range of motion. A normal gait pattern should be maintained also whilst off-loading partially with crutches. Bracing can be used to limit ankle inversion and hence the stress of the injured ligaments. Active movements (focusing on plantar and dorsiflexion initially and then also on inversion and eversion) and passive movements (e.g. standing ankle dorsiflexion) should be performed by the athlete and may also be combined with passive mobilization of the ankle, subtalar and midtarsal joints [16, 28].

35.3.2.2 Proprioception and Balance Training

Proprioception and balance training are essential parts of the rehabilitation after a lateral ligament sprain [16] and should be incorporated in all phases of the rehabilitation with increasing levels of difficulty. Progression can be made from static exercises on a stable surface (e.g. one-legged balance) to standing on unstable surfaces (e.g. wobble board or balance mat), to

Table 35.1 Exercise rehabilitation programme after a grade I–II ankle sprain[a]

Week[b]	Exercise	Progression	Frequency	Additional
1–2	Active ROM exercises dorsiflexion and plantar flexion	Inversion and eversion when symptoms allow, passive movement	1 min, several times per day	Concomitant alternative training, cardiovascular training, e.g. pool and cycling
	Postural stability: Single-leg standing	Uneven surface, eyes closed, perturbations	5 min, twice per day	
	Muscle strength: Peroneus exercise with resistance band, heel raises, hip and trunk exercises	Increase band resistance, double-leg to single-leg heel raises, add external weights	2–3 sets of 10–12 repetitions, once per day	
3–4[c]	Jumping exercises, e.g. on and off a step	Multiple directions, added height, landing on uneven surface, plyometrics (e.g. tuck jumps, lateral jumps)	3 sets of 1 min, once per day	Gradually increased workload, approaching that of the rest of the team
4–6	Running exercises, speed and agility	Increased speed and multiple direction changes, figure of 8, shuttle runs	5–10 repetitions, once per day	

ROM range of motion
[a] Adapted from Lin et al. [26] and O'Driscoll et al. [27]
[b] Time frames are not fixed and depend on symptoms, function and overall rehabilitation goals
[c] After regaining full pain-free range of motion

more dynamic balance exercises and ultimately more advanced high-speed tasks such as jumping-landing, skipping and side cutting.

35.3.2.3 Strength Training

Strength training of plantar flexors and dorsiflexors can commence early in the rehabilitation and gradually also introduce inversion and eversion strength exercises. Heel raises and heel walking are used to activate plantar flexors and dorsiflexors, and resistance bands can be used to strengthen the muscles in dorsiflexion, eversion and inversion (Fig. 35.3). As the player progresses through the rehabilitation phases, proximal hip and trunk exercises are included in the programme to restore neuromuscular function and reduce the risk of recurrent injury.

35.3.2.4 Taping/Bracing

An external support can be used in the early phase after an ankle sprain to limit stress to the healing ligaments, reduce pain and swelling and allow progress of functional exercises [24]. The use of a lace-up ankle support or semirigid brace has been shown to improve functional

Fig. 35.3 Peroneus exercise using a resistance band. Photo: Martin Asker, with permission

outcomes after an ankle sprain [29]. Especially in terms of grade III ligament tears, the use of an external support is recommended in the early stages of rehabilitation [24]. There is also strong evidence that wearing a prophylactic ankle support using either taping or bracing at RTP reduces re-injury risk [16, 22]. Therefore, when more strenuous exercises are introduced in the rehabilitation as well as when the player returns to team training and match play, continued use of tape or brace is recommended for at least 6–8 weeks [29] or longer (often until the end of the season) if the player has remaining instability (Fig. 35.4).

35.3.3 Other Ankle Sprains

The syndesmosis complex comprises the anterior and posterior inferior tibiofibular ligaments, the interosseous ligament and the transverse tibiofibular ligament. Syndesmosis injury is seen in 1–18% of all ankle sprains, most commonly occurring as a result of forceful internal rotation of the leg with external rotation of the talus on a planted foot [16, 21] or with the ankle in dorsiflexion and pronation [30]. Non-surgical treatment for grade I and II stable syndesmotic injuries has shown good results [21, 31]. Initial immobilization and non-weight-bearing is recommended for the first week, followed by 1–2 weeks of partial weight-bearing before full weight-bearing is started [31]. The rehabilitation programme is then similar to that of a lateral ligament sprain, whilst a more conservative approach with protection of the syndesmosis against extreme dorsiflexion and plantar flexion in weight-bearing is advocated [16]. A slower recovery can also be expected with full-load tolerance (e.g. one-legged jumping) usually possible after 6–8 weeks after injury [30]. For unstable grade II and III syndesmotic injuries, and injuries with concomitant rupture of the deltoid ligament, surgery is necessary [31], and a prolonged recovery is expected with RTP after 8–12 weeks.


Fig. 35.4 At return to play after a lateral ligament sprain, a semirigid brace can be used during training and matches to reduce the risk of recurrence. Photo: Martin Asker, with permission

Medial ligament sprains are less frequent in handball and usually occur as a result of player contact. The injury mechanism can include pronation and eversion, external rotation, supination and external rotation or abduction [30]. The medial deltoid ligament consists of a superficial and a deep component. Parts of the superficial component cross both the ankle and the subtalar joints, whilst the deep component only crosses the ankle joint [21]. Isolated injury to the superficial deltoid has a good prognosis, whilst injury to both components usually is more severe and associated with other concomitant soft tissue and bony injuries such as lateral ligaments and syndesmosis and lateral malleolar and fibular fractures [30]. Superficial partial tears are usually immobilized for up to 1 week and then exercise rehabilitation, similar to that for lateral sprains (although instability and recurrences are less frequent), commence. Return to full weight-bearing and training is expected in 6–8 weeks. More significant deltoid injuries may require surgery.

35.3.4 Peroneal Tendon Injuries

The peroneus brevis and longus muscles stabilize the ankle joint and plantar flex the ankle and evert the foot. It is estimated that they provide approximately two-thirds of hindfoot eversion power [32]. Their tendons lie laterally to the subtalar joint line and pass in the same synovial sheath behind the lateral malleolus in a fibro-osseous tunnel [21]. The peroneus brevis and longus tendons are perched along the distal fibula and are prone to injury with inversion trauma of the ankle. It is estimated that up to one-third of patients undergoing surgery for ankle instability may have concomitant peroneal tendon pathology. Traumatic subluxation and dislocation of the tendons are most common and caused by a forceful contraction of the peroneus muscles [32]. A painful clicking is often perceived by patients. Peroneus brevis tears are more common than peroneus longus tears and often result from repeated subluxation, whereby the tendon glides over the sharp posterolateral edge of the fibula. Persistent swelling along the course of the peroneals is commonly seen. Peroneus longus tears can occur in isolation or in conjunction with peroneus brevis tears, as a result of chronic stress or acute inversion injury and forced eversion of a supinated foot [32]. Pain may be localized to the cuboid groove and the plantar aspect of the foot. Non-surgical treatment is initially tested for partial tears and for patients with minor symptoms using neuromuscular restoration exercises. Periods of immobilization in a boot or cast may be used, as well as unloading the peroneal tendons by using a lateral wedge orthosis [32]. Surgery is recommended for patients where non-surgical management has failed and symptoms persist. For athletes with acute longitudinal tears, direct repair may be performed [21]. Similarly, acute ruptures of the peroneal retinaculum with subluxation of the peroneal tendons has poor outcome with non-surgical treatment. Surgery should be aimed at treating the tendon pathology as well as any underlying disorder, e.g. lateral ligamentous instability. Outcomes after peroneal tendon surgery are good with high RTP rates [32].

35.3.5 Midfoot Sprains

Midfoot sprains are less common than ankle sprains in handball but may be difficult to diagnose. Tarsometatarsal joint (Lisfranc) sprains of the foot can be completely ligamentous, osseous or both [5]. The injury can be the result of either direct trauma or indirect as a result of an excessive twisting force or axial force to the plantar-flexed foot. Grade I stable Lisfranc injuries are managed non-operatively with immobilization in a cast or boot and non-weight-bearing for 6 weeks. For unstable grade II and III injuries, surgical stabilization is often necessary and produces good results [5]. The tarsometatarsal joint complex forms a basis of the longitudinal and transverse arches of the foot and is important for midfoot stability. In addition, active stabilization of the midfoot is accomplished by both the intrinsic foot muscles, originating and inserting on the foot, and extrinsic muscles that originate on the lower leg, cross the ankle and insert on the foot [33]. Rehabilitation after a midfoot sprain should thus focus on both the extrinsic lower leg muscles (with a similar approach as for ankle sprains with, e.g. lower leg strength and balance exercises) and the intrinsic muscles of the foot, to support the midfoot and increase stability. Intrinsic foot muscle exercises include, e.g. the ‘short foot exercise’, where the athlete shortens the foot by using intrinsic foot muscles to pull the first metatarsophalangeal joint towards the heel and raise the longitudinal arch of the foot [33]. The athlete should also perform daily strengthening exercises, by walking barefoot on the toes, the heels and the outside and inside of the foot (Fig. 35.5).

35.4 Return to Play After Acute Foot and Ankle Injuries

The risk of re-injury or other subsequent injury is high at RTP. Depending on sex, age group and level of play, re-injuries comprise up to one-third of all ankle sprains whilst slightly less frequent among midfoot sprains. Even if the re-injury risk

Fig. 35.5 Foot extrinsic and intrinsic muscle-strengthening exercises. Photo: Martin Asker, with permission

cannot be completely avoided, it is reasonable to aim for an injury risk that is similar to what is expected for previously non-injured peers in the same sporting environment.

35.4.1 Return to Play: General Principles

The RTP decision is complex and influenced by many medical and non-medical factors. Ideally, the RTP should be as quick and safe as possible. Return to sports may be seen as a continuum from return to participation (i.e. participating in modified or unrestricted training with the team but not yet cleared for full RTP), return to play (i.e. full participation in team training and match play, whilst the athlete may not be performing at the desired level) and return to performance (i.e. where the athlete is performing at the same or higher level of performance as before the injury) [34].

In the RTP process, it is important to consider the short-term as well as long-term risks associated with RTP and what level of risk various stakeholders, e.g. the player, medical team and coach, are willing to accept. The StARRT (Strategic Assessment of Risk and Risk Tolerance) framework [35] outlines factors that may influence the RTP decision:

1. *Assessment of health risk*: with evaluation of tissue health, including patient symptoms (e.g. pain, giving way), medical history (e.g. previous injury) and demographics (e.g. age, sex) as well as physical examination (e.g. swelling, laxity)
2. *Assessment of activity risk*: with evaluation of tissue stresses caused by sports participation, including playing position (e.g. goalkeeper vs winger), competitive level (e.g. professional, amateur), ability to protect (e.g. bracing/taping), psychological readiness, etc.
3. *Assessment of risk tolerance*: including risk tolerance modifiers, such as timing of the season (e.g. preseason vs. playoffs); pressure from the athlete, coach, family, etc.; possibility to mask the injury (e.g. analgesia); etc., that will potentially influence the level of risk the athlete, the coach and the medical team is willing to accept.

35.4.2 Return to Play After Foot and Ankle Injury

There are no scientifically evaluated criteria or guidelines for safe return to handball after a foot/ankle injury. A battery of (subjective and objective) tests is usually required to evaluate the multiple components of physiological and psychological function needed for a safe RTP.

Player self-reports can provide valuable information about the functional readiness to return to handball and aid the RTP decision. Examples of such instruments are the Foot and Ankle Disability

Index (FADI), the Foot and Ankle Ability Measure (FAAM) and the Foot and Ankle Outcome Score (FAOS), all of which have been used in patients with lateral ankle injury [16]. Player self-reports can also give information about the psychological readiness of the athlete to RTP. Examples of questionnaires are the Injury-Psychological Readiness to Return to Sport (I-PRRS) Scale, the Tampa Scale of Kinesiophobia (TSK) and the Re-injury Anxiety Inventory (RIAI) [36]. The I-PRRS Scale consists of six questions asking the athlete about his or her confidence to RTP on a scale 0–100: (1) overall confidence, (2) confidence to play without pain, (3) confidence to give 100% effort, (4) confidence to not concentrate on the injury, (5) confidence of the injured body part (e.g. ankle/foot) to handle the demands of the situation (e.g. handball training, match play) and (6) confidence in the athlete's skill level/ability [37].

Objective functional testing should also be a part of the RTP decision, and this could include several variables such as range of motion, balance and proprioception, strength and agility and sport-specific function.

Range of motion is measured with a goniometer, using the noninvolved ankle or pre-injury status (if available) as reference. Another simple and reliable test is the weight-bearing dorsiflexion lunge test [38]. The athlete places the foot perpendicular to a wall and lunges the knee towards the wall, then moves the foot farther away from the wall until maximum ankle dorsiflexion is achieved. The distance from the foot to the wall, and the angle between the tibia and the wall, is measured [39].

Balance can be evaluated both with static (e.g. standing on one leg eyes closed, SOLEC) and dynamic (e.g. the Star Excursion Balance Test, SEBT) tests [16]. The SEBT evaluates unilateral dynamic balance and neuromuscular control; it has reported good measurement properties and is sensitive for ankle instability [38] and is associated with lower extremity injury risk in athletes [40].

Strength after foot and ankle injury can be evaluated in several ways, for instance, with unilateral heel raises and with various jump tests [16]. It is recommended to use a battery of jump tests to aid in the RTP decision, e.g. one-leg hop for distance, five hop test for distance and a vertical jump test to evaluate explosive strength and plyometric ability and a side-hop test and figure-8 hop for strength endurance. High-load jump tests also evaluate functional stability of the foot and ankle and whether the player has restored confidence of foot and ankle function.

The ability to change direction, to accelerate and to decelerate is essential for the handball player and also stresses the foot and ankle to a high extent. Several different agility tests are available, e.g. the 505 test that evaluates primarily acceleration/deceleration capacity [41] and the modified agility T-test that focuses on the speed of change of direction [42].

Sport-specific tests (or batteries of tests) used to guide the RTP decision can evaluate, for instance, multiple planes of lower extremity movement, landing after explosive movements, appropriate neuromuscular control, compensatory movement patterns, pain during or after the test and how pain may alter movement, change of direction during sports-like movements, symmetry and lower extremity motor control and trunk control/strength required for the sport [43]. Before the player can return to team training, the mechanism of the injury, e.g. ankle inversion force, should be reproduced in a controlled environment [20]. A set of sport-specific drills with gradually increased loading of the foot and ankle, and increased stress on the healing tissues, can be performed whilst evaluating physical signs and symptoms (e.g. swelling, pain), as well as physiological (e.g. movement pattern, technique) and psychological (e.g. confidence, readiness) function, during and after the exercises. An example of a ten-step programme to be completed before RTP is shown in Fig. 35.6.

35.4.3 Managing Player Workload at Return to Play

In the end stage of the rehabilitation of an injured player in-season, i.e. being close to return to team training, it is important to work together with the

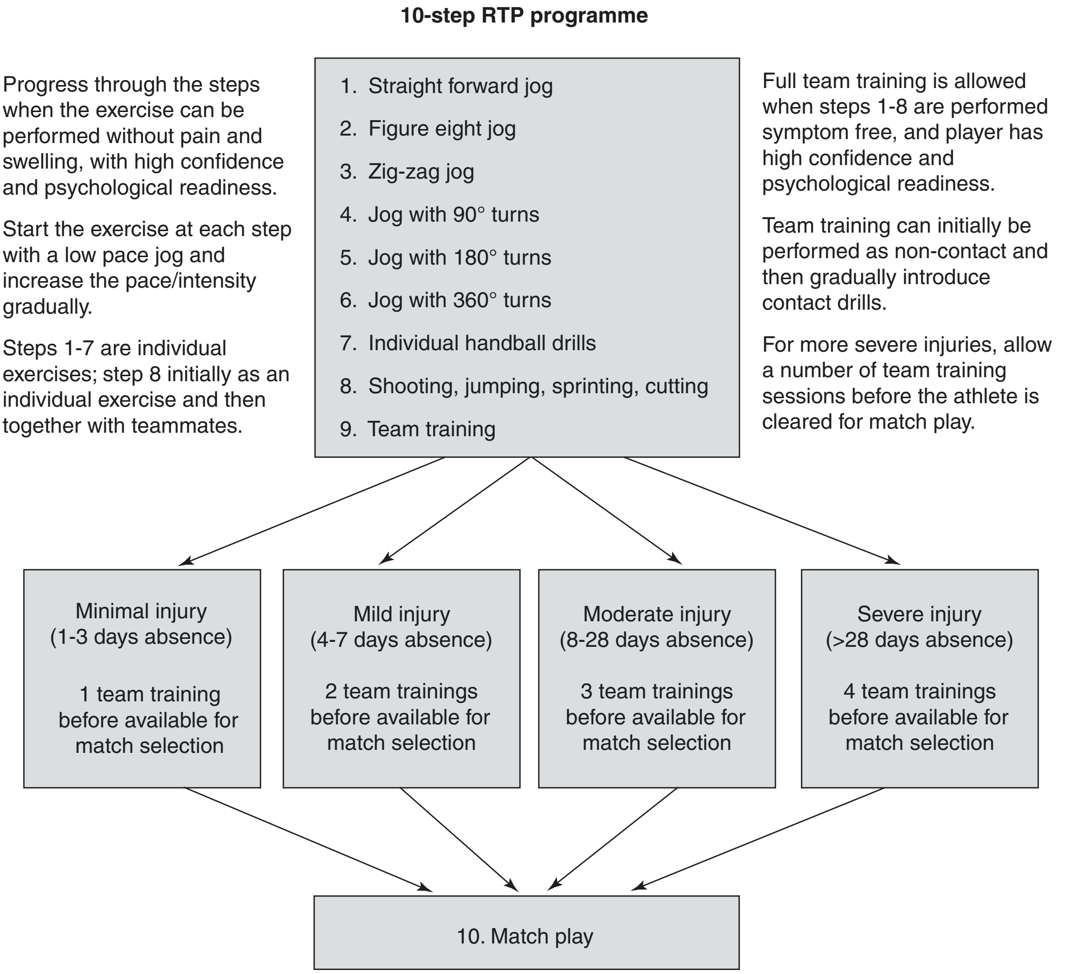

Fig. 35.6 Ten-step return to play programme after an acute soft tissue injury to the foot/ankle. Adapted from Hägglund et al. [44]

coaches and strength and conditioning specialists of the team in order to match the rehabilitation programme to the current team training programme [20]. This is to ensure that the player not only has recovered well from the injury but also has achieved an overall level of fitness to allow him or her to train together with the team and to avoid re-injury or secondary injury. Consideration should thus be given to the amount and intensity of training the player has completed during the rehabilitation period in order to be adequately prepared for match demands. Large spikes in athlete workload may cause negative physiological effects, i.e. fatigue, which has been found to increase injury risk in various team sports [45]. Workload may be monitored during the rehabilitation period by evaluating both external load (e.g. for a handball player, this could be the amount of high-intensity running) and internal load (e.g. by using session rating of perceived exertion) to ensure that the workload is at the level of the rest of the team at RTP. An acute (workload in the current week) to chronic (workload in the last 4 weeks) workload ratio higher than 1.5 has been suggested to put the athlete at high risk for injury [46].

Fact Box: Return to Play after Foot/Ankle Injury

Only limited remaining laxity and normalized range of motion.

High perceived subjective function and no feeling of instability.

Normalized functional test scores (>90% of the uninvolved limb or compared to pre-injury scores) for, e.g. hop tests, balance tests and agility tests.

Player should pass a sport-specific test protocol.

High confidence to perform and psychological readiness.

Use of external ankle support (i.e. bracing or taping) during team training and matches at RTP, for at least 6–8 weeks.

35.5 Take-Home Message

The majority of soft tissue injuries of the foot and ankle that the handball player occur can be treated non-surgically. Re-injury is common, affecting up to one-third of players after return to play from an ankle sprain. Evidence-based measures, such as neuromuscular control training, balance and proprioception exercises and use of external ankle support at return to play, should be implemented, as these are low-cost and effective interventions to reduce recurrence risk. Allowing sufficient time for rehabilitation and evaluating handball-specific function and psychological readiness before returning the player to team training and match play are likely to reduce the re-injury risk further.

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Physical Training in Team Handball

36

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36.1 Introduction

The physical preparation of elite team handball players has become an indispensable part of contemporary professional team handball due to the high fitness level required to cope with the ever-increasing demands of match play. The investigation of the key performance outcomes in team handball practice (see Chap. 20) provides sport scientists, coaches and physical trainers with a framework for optimal planning of training. With this in mind, the aim of this chapter is to provide a general overview of the physical training principles and methodologies commonly implemented in team handball, inclusive of aerobic, anaerobic and strength training prescription.

36.2 Aerobic Training

Aerobic training sessions challenge the cardiorespiratory and metabolic systems by promoting the combustion of carbohydrates and fats in the presence of oxygen. From a physiological perspective, the most effective stimulus is induced by stressing the maximal aerobic uptake (VO_{2max}) or by working at a high percentage of VO_{2max} [1, 2]. This is necessary to enhance oxygen transportation and availability during oxidative metabolism processes. In practical terms, athletes should spend a certain amount of time (T-VO_{2max}) in their target training zone which is generally between 85 and 100% of VO_{2max}. As a consequence, physical trainers in team handball should prescribe training methodologies that require players to sustain continuous type activities for long periods of time above the minimal threshold specified in their target training zone.

A well-developed aerobic system allows team handball players to tolerate the high intensities and physiological load of the daily training, in addition to enhancing recovery between training sessions and competitions. This is especially important during long tournaments where numerous matches are played in a short period of time [3]. To date, most studies aiming to improve aerobic capabilities in team sports players have investigated the effect of either cardiorespiratory and metabolism-oriented (i.e. high-intensity running training) [4], "mixed" (i.e. repeated shuttle sprints, RSS) or game-based (i.e. small-sided

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games, SSG) [5, 6] training programmes. Interval training (IT) is one of the most common methods used in team handball since, when adequately designed, can induce specific metabolic solicitations and matches the team handball physiological profile. Furthermore, training sessions can be performed on court to heighten specificity and adjusted according to positional demands and the players' individual capabilities.

The effectiveness of this training methodology is optimized since intensity can be individualized and controlled using a reference for the involved workload. This is can be completed either through laboratory [7] or field-based assessments such as the 30–15 (30–15 IFT) [4, 8] or Yo-Yo intermittent fitness tests [3, 9, 10]. The intensity of the prescribed interval bouts can then be individualized and will range between 85 and 105% of their maximal aerobic speed (MAS) determined through laboratory assessment, Yo-Yo tests [3, 9, 10] or 30–15 IFT final speeds (V_{IFT}). The prescription of IT exercise can be manipulated to induce different physiological and performance adaptations and, in turn, help in matching the short- and long-term periodization plans [1]. The recommended list of methodological variables for the IT planning includes:

- Exercise modality
- Work interval intensity
- Work duration
- Number of repetitions
- Number of series
- Duration of rest periods
- Recovery modality (active vs. passive) and intensity

In terms of exercise modality, aerobic IT formats can be classified as either long or moderate intervals which may be performed as repetitive runs. In general, the longer the T-VO_{2max}, the higher solicitation of the VO_{2max}, and as a consequence, greater aerobic effects are induced. In practice, the total work duration of any aerobic training format should be related to the goals of the sessions in terms of T-VO_{2max} and T-VO_{2max}/exercise time ratio, also defined as the effective time spent at T-VO_{2max} in relation to the total training session duration, without neglecting the time necessarily needed to reach the VO_{2max}. The manipulation of different IT formats can induce the physiological responses required for improving aerobic capacities while also matching the specific demands of team handball by recreating on-court game-like situations [6, 11]. In team sports, T-VO_{2max} of 5–7 min is likely sufficient to induce important cardiopulmonary adaptations and for maintenance during tapering periods. To maximize T-VO_{2max} during formal aerobic training, running speeds ranging between 90 and 105% of the minimal velocity associated with the VO_{2max} (vVO_{2max}) have been suggested [1, 2]. These intensities elicit high contributions from aerobic metabolism (above 95% of the total energy) with marginal solicitation of the anaerobic pathways and peripheral effects due to the involvement of the neuromuscular system.

Long IT formats are typically implemented in training sessions lasting between 10 and 20 min and can be implemented using a variety of methodologies (Table 36.1). Passive recovery is commonly recommended between sets, with rest periods lasting 2–3 min in duration. However, if an active recovery is chosen, the rest periods should last at least 3–4 min depending on the duration of the running intervals and should be performed at a submaximal intensity ($\leq$ 40% VO_{2max}) to allow the maintenance of high-intensity outputs during the subsequent interval work periods. Evidence suggests that elite athletes tend to be more efficient in accumulating greater T-VO_{2max} compared to less trained athletes [1]. In addition, the choice of the work interval duration seems to be critical especially at the beginning of the training session when a certain amount of time is necessary to accelerate the VO_2 kinetics until reaching the VO_{2max} [12]. Thus, since the VO_{2max} is not reached on the first work period in short IT formats, an adequate warm-up is strictly recommended.

For short IT formats, the main focus should be applied to adjustments in work and rest periods to maximize the T-VO_{2max}. Team handball physical trainers should design short IT sessions with the goal of being time-efficient and optimizing

Table 36.1 The principles for formal and on-court aerobic training aerobic training

	Duration			
Training methodology	Repetitions (Nr.)	Single repetition (min)	Exercise intensity (% MAS)	Recovery (min)
Long interval training				
(a) Passive inter-set recovery	5–10	2–3	90%	P; 1–2 at 0%
(b) Active inter-set recovery	5–6	3–5	> 90%	A; 2–3 at 40–50%
(c) Active inter-set recovery	3–4 × 2	2	100%	A; 2 at 50%[a] P; 3–4 at 0%[b]
Short interval training				
(a) Passive inter-rep recovery	10–12	(s) 30	90%	(s) P; 30 at 0%
(b) Passive inter-set and inter-rep recovery	2 × 10–20	20	95%	P; 20 at 0%[a] P; 120 at 0%[b]
(c) Passive inter-set and inter-rep recovery	2 × 16–20	15	100%	P; 15 at 0%[a] P; 120 at 0%[b]
(d) Active inter-rep and passive inter-set recovery	2 × 20	10	105%	A; 15–20 at 40–50%[a] P; 120–180 at 0%[b]
On-court aerobic training				
The short interval training modalities b, c and d could be designed as on-court aerobic training formats by converting the final speeds of both laboratory and field-based assessment tests into running distances according to the individual players' own capacity. Coaches and physical trainers should accurately consider and adjust the running paths, amount of high-intensity presence of acceleration and decelerations actions, number of changes of direction (COD) and their directional angles. As general guideline, the greater the amount of accelerations, decelerations and CODs and the more acute the angle of the COD, the higher the neuromuscular responses and the contribution of the peripheral system				

The exercise intensity is expressed in percentage of the maximal aerobic speed (MAS). The recovery modality is expressed as active (A) or passive (P); whether active the designed intensity is expressed as relative to MAS as well

[a] Between repetition

[b] Between series

the T-VO_{2max}/exercise time ratio. Keeping in mind the importance of VO_2 kinetics for improving the T-VO_{2max}, it is suggested to perform short IT training sessions organized in 2–3 series of 8–12 min and include short bouts (10–20 repetitions of 10–30s) of formal running at intensities between 90 and 105% of vVO_{2max} interspersed by rest periods of fixed or similar durations [13]. The characteristics and intensity of the rest interval play a major role in determining the contribution of aerobic pathways during IT due to its effect on the exercise $VO_{2.}$ Also the total exercise duration should be considered as this will indirectly alter the T-VO_{2max}. In general, compared to short IT formats with passive recovery, exercise modalities involving active recovery are 30–60% shorter in terms of total work duration. In these scenarios, the manipulation of the active recovery intensity ensures a similar absolute T-VO_{2max} regardless of the lower total work time. The implementation of active recovery modalities has been shown to compensate for the relatively shorter duration of total work time, inducing substantially greater T-VO_{2max} and T-VO_{2max}/exercise time ratio outcomes when compared to exercise modalities of similar work intensities but including passive recovery [14]. More precisely, the intensity of the active recovery represents a factor worthy of consideration when designing and planning IT sessions. In fact, the recovery intensity likely dictates the effectiveness of the training sessions' ability to increase both the T-VO_{2max} and T-VO_{2max}/exercise time ratio. However, the effects can be highly variable, with improvements ranging from small to very large in the above-mentioned metabolic indexes. The current literature suggests that for team-sport athletes performing very short IT formats including 10–30s run bouts, rest periods ≤15–20s at an intensity around 40–50% of VO_{2max} [1].

Key Points of Aerobic Training

- Necessary preliminary aerobic capacity assessment
- Training target zones between 85 and 100% of VO_{2max}
- Individualized intensity
- Training format (long and/or short IT with active or passive recovery) selection according to the specific demands (T-VO_{2max} and T-VO_{2max}/exercise time ratio)
- Continuous running (e.g. 15 min at 90% of maximal heart rate)
- Low-intensity running as recovery training

36.3 Anaerobic Training

Previously, working demand analyses of elite team handball have been performed ([3, 15–21]; see Chap. 3). These study data indicate a high need for superior acceleration and deceleration capacity, high rates of force development (RFD) and a high ability to perform explosive jumps, fast and hard shots, rapid side-cutting manoeuvres, powerful changes of direction and agility movements and strength-demanding physical confrontations, e.g. tackles and screenings. In addition, the intermittent high-intensity running capacity also seems crucial for playing performance [16, 17].

Based on scientific data [15–17 20], high-intensity running does not represent much of total effective playing time. However, the ability to continuously change pace and accelerate throughout the entire match is likely of high importance for top-level playing performance. Thus, an intensified focus on anaerobic training aspects and resistance training seems highly relevant especially for male elite team handball players [22]. It is clear that anaerobic exercises should be a key focus with regard to the training of elite team handball players for improving their ability to repeatedly perform anaerobic exercise and to rapidly recover after periods of high-intensity exercise. Consequently, the players will be more capable of performing the above playing actions at sustained high levels throughout the entire match. Even though almost all kind of strength training is anaerobic of nature (due to the high intensity and short exercise duration), it is described in a separate section.

36.3.1 Anaerobic Training

Anaerobic training can be divided into two main training areas ([11]; see Table 36.1):

- Speed training
- Speed endurance training
  The latter can be further divided into:
- Production training
- Maintenance training

The benefits of anaerobic training for elite team handball players are an improved performance of intense match activities such as accelerations, change of directions, jumps, shots and tackles and furthermore an elevated ability to perform very high-intensity exercise more frequently and for longer time periods. These three training areas – speed training, production training and maintenance training – are overlapping (see Table 36.2). They are all performed with a much higher intensity than in aerobic training, i.e. with an intensity corresponding to over VO_2-max [23]. Consequently, all anaerobic training must be performed according to the interval

Table 36.2 The principles for formal anaerobic training

Training area	Duration		Exercise intensity	No. of repetitions
	Exercise (s)	Rest		
Speed training	2–10	>10 times exercise duration	100%	2–15
Production training	10–40	>10 times exercise duration	60–100%	2–15
Maintenance training	10–120	3–5 times exercise duration	30–100%	2–15

The exercise intensity is expressed in percentage of the individual maximal exercise intensity. When the training is conducted with the ball, the ratio between the duration of exercise and rest/active recovery can often be reduced compared to the values presented, since the players are not constantly working at high intensities due to natural variations in the game

principle. Large quantities of anaerobic training should only be performed at an elite level, since it is a physical and mentally demanding type of training. Since the effects of anaerobic training mostly occur in the muscles used during training, anaerobic training in elite team handball should be performed on court with a ball, i.e. conducted in a manner similar to actual team handball match play.

In speed training, the players must exercise with maximal intensity for short periods of time (less than 10 s). Thus, it is no problem to find the right training intensity. It may be harder during on-court speed endurance training, but with experience it will be easier. If the training is performed as formal running, it is relatively easy to control the intensity, as the correct load can be found as a certain time relative to the time at the distance in question, when maximal exercise is performed a single time.

Since the intensity of anaerobic training is very high, it requires great motivation from the players to complete. Measurement of heart rate can be utilized during speed endurance training sessions as an indicator of whether the training is being conducted with sufficient intensity. For longer periods of exercise (> 1 min), the heart rate should be close to maximal values at the end of the exercise periods. However, for short periods of work (<1 min), the heart rate will not be able reach maximal values and therefore cannot be used to assess the training intensity.

36.3.2 Speed Training

The aims of *speed training* are to increase the ability to perceive match situations, to take immediate actions when needed and finally to increase the ability to rapidly produce force during high-intensity exercise. During speed training, the players should perform maximally each time for less than 10 s.

There are three key factors in the concept of speed:

- Reaction speed, which is the ability to react quickly and efficiently at the starting time
- Acceleration capacity, which is the ability to quickly increase the speed from zero to maximum
- Maximum running speed, which is the players' highest speed

Match analyses of elite team handball have shown that speed training in team handball primarily should target reaction speed and acceleration capacity (i.e. RFD) rather than focus on maximum running speed [16, 17]. The mean duration of a sprint action was calculated to be 1.0 s corresponding to a running distance covered of approximately 7 m [16]. Thus, in team handball it is important to react quickly and perform powerful changes in direction while moving quickly over short distances (< 15 m).

When team handball players are required to react quickly at the start of a fast break or during a quick breakthrough, rapid force production is required in limited time frames to effectively perform game-specific activities. It usually takes about half a second to achieve maximum force in the skeletal muscle [24, 25]. The ability to generate high RFD is often more important in team handball than high maximum strength. This ability is trained by heavy, explosive strength training (also called RFD training), and strength training is therefore an important supplement to the actual speed training in team handball. The result of such strength training will be, e.g. an increased acceleration ability, if the effect of strength training is "transferred" to the right movement pattern during match play via functional speed training [11].

Most of the physiological effects of speed training are derived from adaptations in the central nervous system (spinal cord and brain) and its interaction with the recruited musculature. Therefore, it is pivotal that this interaction is trained under situations that are most similar to the situation during match play. This means under conditions where the training drills are performed with maximum effort with fresh muscles, where the coordination pattern is trained with the muscle fibres activated in the right order at the right speed [23]. Furthermore, training regimens for the development of speed should also include a lot of coordination and strength training exercises. The fundamentals of sprint mechanics must be trained, even in team handball. When moving as fast as possible, the players must be able to perform the correct technique automatically, as there is no time to think about this during the actual performance during match play. However, another approach could be to physical overload especially players with poor technical skills, since they will not be able to perform on-court speed exercise drills with maximal intensity. This will require formal speed training in non-match situations. These training effects should then be incorporated into match play be performing on-court speed training with the ball. This interesting concept needs to be examined in future studies.

Speed training should be performed in the beginning of the training session when the players are not tired and after a proper warm-up. Speed training should mainly be performed as on-court functional speed training performed with the ball in match-like situations instead of formal speed training, since part of the desired training effect is to improve the player's ability to anticipate, evaluate and decide in different situations in team handball, e.g. the start signal could be the completion of a shot or the bounce of a ball. In team handball, speed is not just a matter of physical capacity; it also involves quick decisions that must then be transferred into fast actions. When formal sprinting without a ball, e.g. running after signal from the trainer, it is mainly the acceleration capacity and the ability to fast anaerobic energy turnover that is trained. This form of training can only be used to a small extent to train the reaction speed in team handball, as the specific signals (e.g. whistle) the players react do not exactly resemble those they are exposed to during match play [11]. However, as mentioned earlier this training may be relevant in special situations when trying to physical overload players with poor technical skills.

Additionally, during match play sprinting there are usually directional changes depending on where the opponents are or where the ball is when passed between players. Often the accelerations/decelerations occur with whole or partial body contact with opponent players. In team handball, the player's coordination pattern when sprinting is therefore a lot different than, for example, when sprinting in track and field. As the training specificity is high, it means that certain muscle fibres used during sprinting in team handball are not trained and others are trained in the wrong movement pattern [23].

The periods between the exercise bouts should be long enough for the muscles to recover to near resting conditions to enable the players to perform maximally in subsequent exercise bouts. Previous studies have shown that the performance of repeated sprints can be maintained, if the duration of the pauses is more than ten times the length of exercise period [26]. The longer the exercise time (sprint distance), the higher the relationship between the duration of exercise period and the pause must be. Speed training should therefore be carried out with at least a pause duration of ten times the length of exercise period to be effective. High concentration and great will are essential for achieving an optimal training effect.

Key Points for Speed Training

- Thorough warm-up
- Maximal intensity

- High concentration and motivation
- Few repetitions
- Long pauses, exercise-to-rest/active recovery ratio >1:10
- Should be performed in the start of the training session
- Should mostly be performed with the ball

36.3.3 Speed Endurance Training

The purpose of *production training* is to increase the ability to rapidly produce power and energy via the anaerobic energy-producing systems and thus improve the ability to perform maximally for a relatively brief period, whereas the aim of *maintenance training* is to increase the capacity to continuously produce power and energy through the same energy systems and hereby improve the ability to sustain exercise at a high intensity. Both training regimens also aim to increase the ability to recover after very high-intensity exercise.

Findings of high post-match blood lactate concentrations of 2–10 mM in elite team handball players in connection with tournament matches [3] indicate that the glycolytic energy system is highly stimulated during certain periods of the game. Moreover, match analyses of elite team handball have revealed that the amount of high-intensity running may be very high in brief time intervals, and indications of temporary fatigue and impaired physical performance have been observed reflected by a reduced amount of high-intensity running and technical playing actions in the second half [16–18]. Additionally, the ability to continuously exercise at very high intensities throughout the entire match seems to be crucial for top-level playing performance in team handball. Consequently, *speed endurance training* including training of the repeated sprint ability must be an integrated part of the physical training for elite team handball players.

36.3.4 Production Training

If team handball players during match play, e.g. are performing a fast break immediately followed by a quick retreat and some intensive defensive actions in a relative brief period of time, they must be able to produce a high amount of energy very fast. Production training increases the ability to break down ATP and PCr quickly, as well as increasing the maximum rate of the glycolysis. A high exercise intensity is essential for increasing the rate of these energy systems, and the intensity should not be less than 60% of the maximum exercise intensity. The duration of the individual exercise bout should not be too short, because it takes about 10 s before the glycolysis runs at maximum velocity [23]. The exercise bouts less than 10 s are too short for optimal training effects on the anaerobic metabolism. Conversely, the exercise periods should not be longer than 40 s, as it is approximately the limit for how long such intensity can be maintained when the exercise is repeated several times one after the other during a single training session. Consequently, in production training the duration of the exercise bouts should be relatively short (10–40 s), and the rest periods in between should be comparatively long (2–7 min) to maintain a very high intensity throughout the training.

Production training should take place with long rest periods [27]. In experiments where 6 s of maximum intensity on a bike were repeated ten times with 30 s pause in between each sprint bout, the rate of the glycolysis decreased markedly as the bouts were repeated. The exercise-to-pause ratio was 1:5 and not sufficiently high to maintain a high glycolysis rate. Thus, the training effect on the maximum glycolysis rate was not optimal. Production training should therefore at maximum intensity be carried out with at least a pause duration of ten times the length of the exercise period to be as effective as possible (see Table 36.1).

Production training is normally placed at the end of the training session, as the training is so physical and psychologically demanding that the players may be affected for a while afterwards. Sometimes it may be an advantage to place production training early in the training session. Especially if the players have been training for a long time – e.g. more than 1 h of team handball training – before the actual production training, you may risk that many muscle fibres are completely or partially emptied of glycogen when the production training starts. This makes it difficult to recruit sufficient muscle fibres and maintain an exercise intensity within the primary area of production training [23]. However, it is not recommended to train technical skills after production training.

Key Points for Production Training

- Short exercise periods at 60–100% of maximum intensity
- Long pauses, exercise-to-rest/active recovery ratio > 1:10
- Normally placed in the end of the training session
- Should be performed with the ball
- Should be followed by recovery activities
- Performed primarily at the elite level

36.3.5 Maintenance Training

When team handball players during match play are performing a very intensive organized offensive or defensive play, or are performing numerous fast breaks and quick retreats right after each other, they must be able to maintain a high exercise intensity for a prolonged time period even though they are beginning to become fatigued. When training to increase the ability to tolerate, neutralize and eliminate fatigue substances in the working muscles, the exercise intensity must also be high. In maintenance training, the exercise periods should be 10–120 s, whereas the duration of the rest periods should only be a little longer than the exercise periods, if the training is performed with a ball, so that the players become progressively fatigued (see Table 36.1). Maintenance training should be performed at the end of the training session, because the training is so demanding that players will be physically affected for a long time afterwards [23].

As the training gradually becomes more strenuous to the player, it is important to continue with the highest possible intensity. It is a matter of achieving a high accumulation of fatigue substances, so that the muscles in this way can increase the ability to tolerate, neutralize and eliminate the accumulated fatigue substances. The pauses between the exercise bouts must be relatively short (three to five times the length of exercise periods), as the players at next repetition already from the start should have an increased concentration of fatigue substances in the muscles [11]. However, the pauses must not be too short, as it is thus not possible to maintain the exercise intensity within the primary area of tolerance training, and the training effect in the last exercise periods will be too low. The exercise periods should not be longer than 2 min, as it is approximately the limit for how long an intensity corresponding to just over VO_2-max (~30% of maximum intensity) can be maintained when the exercise is repeated several times one after the other during a single training session [23]. If the players are very well-trained (faster recovery), the pauses can be shorter. Often, team handball players do not have sufficient patience to complete the initial exercise bouts with proper low intensity. Furthermore, it is also important for the unexperienced player not to make the pauses too short.

Key Points for Maintenance Training

- Exercise intensity at 30–100% of maximum intensity
- Relatively short pauses/active recovery, three to five times exercise duration
- Must be performed at the end of the training session
- Should be performed with the ball
- Should be followed by recovery activities
- Performed primarily at the elite level

In exercise drills with the ball during all kinds of anaerobic training, the intensity of each player depends on how many players are involved in the drill. With many players, situations will often occur, e.g. when the ball is far away from the player or when the ball is out of play, where the player's intensity will decrease, and therefore the duration of the pauses can be reduced compared to the length of the exercise. With few players in an exercise drill, it is easier to control the intensity of the individual player, and there will be fewer periods where the intensity is not high enough. It is important that there always is access to many balls, so that there is no break in the exercises.

36.4 Strength Training

In team handball, as for many other team sports, the design and methodological application of strength training modalities should address two main objectives: injury prevention and performance enhancement. In light of the strenuous nature of the team handball discipline, involving high-intensity short-duration activities such as sprinting, jumping, turning, pushing, blocking, throwing and ability to perform effective defensive interventions [16, 22], a systematic and progressive strength training plan could lead to the improvement of specific capabilities representing the physical prerequisite for successful participation at elite level [28].

In order to design an efficient strength training programme in team handball, it is fundamental for physical trainers to have a wide understanding of the game performance model and the respective demands (see Chap. 10) in terms of specificity. Specificity is a crucial aspect to consider when trying to transfer the physical improvements achieved through physical training programmes into playing performance [29]. It is widely documented that any specific physical training programme should be carried out matching a comprehensive analysis of the playing demands (see Chap. 20). The key training principles for strength training in team handball and the biomechanical aspects regarding the nature of their execution and the training contents and modalities commonly adopted are described in this section.

36.4.1 Strength Training Methodology for Developing Athletes

A team handball player's career can easily span around 20 years, and, as a consequence, strength training programmes should be designed and developed with a long-term athletic development focus. Although certain phases of a team handball player's development or specific positional demands due to his role may require attention, the strength training journey may be considered as a long-term model with well-defined objectives, contents and methodologies for each stage. The best approach to design individualized strength training programmes for team handball players consist in firstly to collect information about their injury history, then assess strength and weaknesses and finally create a progressive plan which takes into consideration the needs to develop strength capabilities which can both positively affect performance and limit future injury occurrence.

In literature, little is known about the most appropriate approaches for a periodized strength training programme. In our experience, strength training should be realized considering consecutive stages leading to a progressive and resilient development of future athletes. Indeed, an accurate planning, made by the coaching staff, is required for appropriately managing the overall loading experienced by the athletes in order to avoid unfunctional overreaching and/or overtraining effects. From a methodological perspective, strength training should be performed weekly with one to three sessions per week according to the targeted objectives, the training schedule and the congested matches' fixture. As common practice, two sessions per week can be useful to improve strength and power in well-trained individuals [9, 10, 30–32], with three sessions per week being more appropriate in pre-season or intensive preparation periods. Single sessions per week are unlikely to produce significant improvements in strength and power but can be useful to maintain strength and power levels in well-trained players [28, 33, 34].

The training contents selection and the associated load progression should include some elements of heavy strength training focusing on cumulative muscular adaptations with emphasis on hypertrophy and maximal strength development. The following training stages should address explosive force, muscle power and rate of force development (RFD) with the aim to induce transfer effects on the specific handball-related skill performances. Accordingly, the training methodologies can systematically vary over the course of the athletes' development. Evidences suggest larger volumes of progressive heavier loads (>80% of 1RM) at the beginning of the career, in case of young in-development athletes, or during in-season phases in professional teams. Then, the emphasis is shifted gradually to larger volumes of lighter loads (loads aiming to maximize impulse-dependent mechanical capabilities such as RFD and power) and more explosive movements with an overall reduction of training volume towards later stages of development or in very congested in-season periods. As general rule, the ultimate objective of an ideal approach should be to effectively improve the force/velocity and power/velocity relationships [35] thus optimizing neuromuscular adaptations. Table 36.3 details the main stages to consider for an appropriate strength training development with both the training principles and methodological guidelines targeting their associated objectives.

36.4.2 Training Specificity: The Force Vector Hypothesis

The force vector hypothesis [35] and the principle of movement specificity between functional tasks and the physical activities performed must be carefully considered when designing interven-

Table 36.3 The principles for strength training

Stage	Objectives	Contents	Methodology
1. Introduction to strength training	– Learn to develop force – Control and stabilization of the limbs during basic movement – Focus on technique and control	Multi-joint bodyweight exercises with low resistance such as through using elastic bands, medicine balls or sand bags	2 × 15 reps Rec: 1′ 3 × 8–10 reps Rec: 1′
2. Introduction to general strength and hypertrophy	– Learn to develop force with greater overloads – General strengthening of the musculoskeletal system – Induce appropriate levels of hypertrophy	Multi-joint barbell or resisted exercises such as squat, lunges, deadlift, hip thrust, bench press, overhead press exercises Single or multi-joint exercises with free weights or dumbbell including different pulling and pushing move variations	4–6 × 4–6 reps loaded 80–85% 1 RM Rec: > 2′ 3–4 × 10–12 reps loaded 60–80% 1 RM Rec: 1′–1′30″
3. Maximal strength training	– Maximize and maintain strength levels by the regular use of key strength exercises	Multi-joint barbell or resisted exercises such as squat, lunges, deadlift, hip thrust, bench press, overhead press exercises Large use of weightlifting techniques where appropriate	4–6 × 2–5 reps loaded 85–95% 1 RM Rec: > 3′ Periodization models according to the competitive schedule and development level
4. Power training	– Learn to develop force rapidly emphasizing rapid speed of movement with increasing resistance	Bodyweight hops, jumps drop jumps, barbell jump squats Medicine ball throws, bench throws, push presses	3–5 × 6–10 reps Rec: 1′–2′ 3–5 × 4–6 reps loaded 30–50% 1 RM Rec: > 2′
5. Explosive strength or rate of force development (RFD) training	– Learn to develop the maximum amount of force or impulse in a minimum amount of time	Multi-joint barbell or resisted exercises such as squat, lunges, deadlift, hip thrust, bench press, overhead press exercises Olympic weightlifting such as cleans, power cleans, snatches, jerks	3–5 × 2–4 reps loaded 30–70% 1 RM Rec: > 2′ 3–5 × 1–2 reps loaded >85% 1 RM Rec: > 3′

The exercise intensity is expressed in percentage of the one-repetition maximum (1RM) tions to achieve the desired adaptation. Recently, it has been suggested that performance adaptations to strength training may occur through the specificity of the force vector application which provides transfer effects towards the specificity of the sporting performance demanding a similar force production and application [30]. For example, hip thrust exercises have been shown to be more effective than squat exercises for improving acceleration and sprinting tasks due to the similarity in the motor pattern, hip and knee joint involvement and force orientation production [31, 36]. Similar trends were found with regard to change of direction drills, and the same conclusions were drawn following plyometric training with team handball players [30]. These findings have a great potential for team handball players since strength training programmes implementing the force vector specificity principle may be prescribed as specifically oriented exercises, which improve force production and related functional physical performance according to the specific task, the performance model and playing demands in team handball.

36.4.3 Training Contents and Modalities

In keeping with the specificity principle mentioned above, the strength training programme must be directed at improving the force production capacity of the upper and lower limb muscles. This approach will aid in force transfer within and between the body structures and promote their long-term resilience due to the continuous involvement into repetitive and high-intensity demanding actions. Planning a periodization programme for team handball players is complicated by the many diverse factors affecting performance. Beside them, it is worth to consider players' gender and their maturation stage, competitive level, length of the competitive season, phase of the season, training experience in general and for resistance training in details, playing position, special needs, weaknesses and previous injury record. In general, when considering the time course of the specific adaptations induced by strength training contents commonly used in team handball, it is useful to categorize the induced effects in acute or short-term adaptations and chronic or long-term adaptations.

36.4.3.1 Acute or Short-Term Adaptations

Strength training and the different resistance exercise variants are recognized as beneficial training tools for acutely enhancing functional tasks, according to the known phenomenon called post-activation potentiation (PAP) [37]. PAP refers to the acute enhancement of muscular function as a direct result of its contractile history [37]. The literature suggests that the PAP effects may be affected by several physiological and training variables including the type of exercising muscle fibres [37]; the subject's fitness characteristics; the type, duration, volume and intensity [38] of the conditioning activity (CA) used for achieving the potentiation effects [39]; the length of the period following the CA [40]; and the type of subsequent activity [39]. Recently, in team handball, Dello Iacono et al. [41] reported a potentiation effect on 25 m sprints and change of direction ability after 8 min following a protocol including horizontal-alternate one-leg drop jumps. In light of the acute biomechanical adaptations associated with PAP protocols, the applicability of training regimens in terms of PAP exercises is recommended to coaches and team handball players as either warm-up strategies aiming to acutely improve subsequent functional performances or as part of complex programmes of sprinting training [31].

36.4.3.2 Chronic or Long-Term Adaptations

Strength training regimens are widely recognized as potential tools for enhancing sports performance and have been extensively correlated with specific motor tasks and physical requirements of the athletic models of interest. Scientific studies generally report strength training regimens to be an effective mean for improving strength capabilities and explosive neuromuscular impulse-dependent components such as acceleration, jumping, sprinting, change of direction (COD)

Table 36.4 Current evidences for strength training in team handball

Study	Population	Duration	Methodology	Performance outcomes
Barata [34]	12 male amateur players	9 weeks (3 sessions/ week)	Full-body training (8 exercises) 2–3 sets × 8 (light overload: 1–12 kg)	↑ 3.7–6.9% throw speed release
Marques and González-Badillo [32]	16 male professional players	12 weeks (2–3 sessions/ week)	Complex training (bench press, squat, squat jumps, countermovement jumps, box jumps, sprints) 2–3 sets × 3–6 at 70–95% 1RM	↑ 3.3% 30-m sprint ↑ 2.3% 15-m sprint ↑ 6% throw speed ↑ 20.8% loaded (20 kg) CMJ ↑ 25.8% loaded (40 kg) CMJ ↑ 13% CMJ ↑ 27.7% $1RM_{BP}$
Dello Iacono et al. [6]	18 male professional players	10 weeks (2 sessions/ week)	5–8 sets × 6–10 VDJ or HDJ (25 cm)	↑ 3.7–8.1% 10-m sprint ↑ 7.8% COD ↑ 3.7–4.1% 25-m sprint with COD ↑ 3–8.6% CMJ
Gløsen [42]	10 female first-third national level	8 weeks (3 sessions/ week)	3 sets × 6 pulley exercise (85% 1RM)	↑ 2% throw speed release
Gorostiaga et al. [43]	10 male adolescent players	6 weeks (2 sessions/ week)	Squat, leg press, knee flexion curl, bench press, pec dec 1 set × 12–10–6-3 at 40–50–80–90% 1RM	↑ 12.2% $1RM_{LP}$ ↑ 22.9% $1RM_{PD}$ ↑ 13.3% isometric unilateral leg extension force ↑ 9% isometric unilateral leg flexion force ↑ 3.2% throw speed
Hermassi et al. [10]	26 male professional players	10 weeks (2 sessions/ week)	2–3 sets × 4–6 squat, bench press and pullover (80–95% 1RM)	↑ 42.4% run-up throw speed ↑ 33.3% throw speed ↑ 14.7% $1RM_{BP}$ ↑ 50.1% $1RM_{PU}$
			2–4 sets × 3–6 squat, bench press and pullover (55–55% 1RM)	↑ 37.6% run-up throw speed ↑ 23.8% $1RM_{BP}$ ↑ 6.5% $1RM_{PU}$
Hermassi et al. [44]	34 male elite players	8 weeks (3 sessions/ week)	Throws with 3-kg medicine balls	↑ 24.2% standing throw speed ↑ 22.1% jump throw speed ↑ 22.4% run-up throw speed ↑ 19.1%$1RM_{BP}$ ↑ 29.1%$1RM_{PU}$
Ettema et al. [45]	7 female sub-elite players	8 weeks (3 sessions/ week)	3 sets × 6 of loaded throws (85% 1RM at a pulley machine)	↑ 6.4% throw speed ↑ 14.3% heavy ball throw speed ↑ 22.9% throw task 1RM

Study	Population	Duration	Methodology	Performance outcomes
Hoff and Almasbakk [46]	6 female second national level	9 weeks (3 sessions/week)	3 sets × 5–6 bench press exercise (85% 1RM)	↑ 17–18% throw speed release
Raeder et al. [2]	28 female amateur players	6 weeks (3 sessions/week)	1–3 sets × 6–12 throws with 1- and 2-kg medicine balls	↑ 14.3% standing throw speed ↑ 15.4% shoulder moment IR_{180}
Sabido et al. [47]	28 male junior players	4 weeks (2 sessions/week)	Rebound BP throw (30–50–70% 1RM)	↑ 9.1–9.6% $1RM_{BP}$ ↑ 3.4–4.7% standing throw speed ↑ 3.4–5.3% jumping throw speed

Note: *RM* maximal repetition; *CMJ* countermovement jump; *JR* jump and reach; *1RMBP* 1 maximal repetition in bench press exercise; *COD* change of direction; *BP* bench press; *1RMPU* 1 maximal repetition in pullover exercise; *IR180* isokinetic internal rotation moment at 180°/s; *1RMLP* 1 maximal repetition in leg press exercise; *1RMPD* 1 maximal repetition in pec dec exercise

ability and throwing [9, 10, 33]. Table 36.4 reports a wide range of training methodologies commonly adopted in the daily team handball practice and the chronic adaptations induced when designed as long-term strategies.

36.5 Summary

In conclusion, strength training is of fundamental importance for the athletic development of team handball players. Importantly, the paucity of data in the literature on the strength training applications among elite team handball players requires an accurate understanding when selecting the most effective training prescriptions for elite handball players involved in national and international competitions during very long seasons. Regardless of the limited information available, it appears that strength training can produce beneficial effects when strength programmes are planned consistently and progressively during the entire season. It should be reminded that a specific selection of the appropriate exercise and loading methodologies is needed due to the specific demands of the sport and the different requirements due to the playing positions. In fact, despite general improvements in personal strength levels, as expressed by 1RMs levels, should be aimed, the same adaptations would be worthy of interest if they have a direct influence on handball-specific activities such as acceleration, jumping, sprinting, change of direction (COD) ability, throwing and effective defensive actions.

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37

Stretch-Shortening Cycle Exercises in Young Elite Handball Players: Empirical Findings for Performance Improvement, Injury Prevention, and Practical Recommendations

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37.1 Reactive Strength Training in Youth Elite Handball: Empirical Findings for Performance Improvement, Injury Prevention, and Practical Recommendations

In 2016, two major handball competitions took place in Poland (European Championships) and Brazil (Olympic Games) which clearly indicated the importance of physical fitness for success in handball competition. During these two tournaments, many experts and spectators were astonished by the extraordinary jump performance of the German right wing national team player Tobias Reichmann. His outstanding physical fitness allowed him extra airtime to realize spectacular maneuvers and to increase chances of scoring.

Previously, it has been reported that particularly in elite handball, high levels of jump performance are needed for players of different positions (e.g., back court) to outperform opponents during offensive and defensive actions [1–3]. To accomplish high physical fitness levels as an elite handball player, muscle strength/power, agility, and speed have to be systematically developed during all stages of long-term athlete development in youth handball. Youth athletes' handball training is different from that of elite handball players because individual differences in timing and tempo of growth and maturation have to be taken into account in youth when coaching young talented handball players. Consequently, handball coaches should have profound knowledge in pediatric exercise science and physiology to successfully develop talented players to elite athletes. In this context, Lloyd

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and colleagues [4] published a model on youth physical development that provides useful and evidence-based information on the promotion of physical fitness according to sex and maturity status during the different stages of long-term athlete development. Following this model, agility, speed, and muscle strength/power are important qualities that should be developed pre-, around, and post peak height velocity (PHV). Of note, PHV is the time in which adolescents experience the fastest upward growth. This can be predicted using simple anthropometric measures (sitting and standing height as well as birth date, test date, and body mass) to obtain information on a child's biological maturity status. The University of Saskatchewan, College of Kinesiology, provides an online calculator for the prediction of age at PHV (https://kinesiology.usask.ca/growthutility/phv_ui.php). The underlying regression equations are based on the work of Mirwald et al. [5, 6]. Within these components of physical fitness (i.e., agility, speed, muscle strength/power), the main focus should be laid on the development of muscle strength during all stages of long-term athlete development [4].

Reactive strength training is an appropriate means to promote components of physical fitness in general and muscle strength/power in particular in youth handball players. In fact, it has previously been reported that reactive strength training is an often applied and effective training regimen to enhance youth and elite athletes' muscle strength/power, speed, agility, and throwing performances in handball [7–12]. Reactive strength exercises are characterized by muscle actions in the stretch-shortening cycle (SSC) which is why reactive strength training is a specific form of SSC training. During the SSC, the pre-activated muscle is lengthened in the braking or plyometric phase (i.e., eccentric phase) followed by an immediate muscle shortening in the push off or myometric phase (i.e., concentric phase) [13]. The benefit of movements conducted in the SSC is that performance during myometric (i.e., concentric actions) is enhanced compared to isolated myometric actions that do not take place in the SSC [13, 14]. To improve sport-specific activities conducted in the SSC (e.g., vertical jumps, rapid changes of direction), specifically tailored reactive strength training protocols have to be developed and implemented in youth handball training in terms of training volume, intensity, frequency, etc. [9, 10, 15–18]. For this purpose, this book chapter provides recommendations on the design of effective reactive strength training protocols in young athletes (see Fig. 37.1).

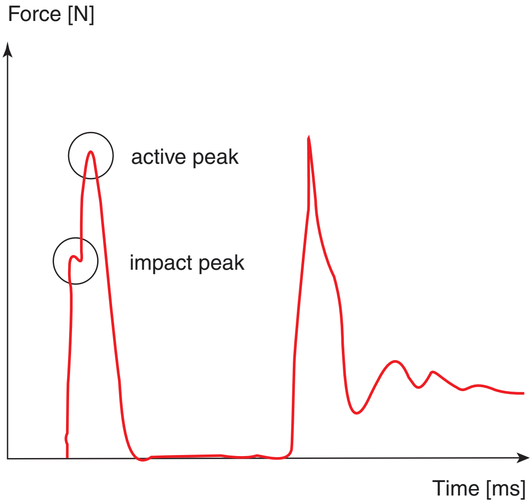

Fig. 37.1 Force-time curve of a drop jump illustrating the impact and the active peak. The impact peak is an indicator of heel touch down during landing

Besides the well-documented performance enhancing effects of reactive strength exercises, numerous studies reported additional effects on lower limb injury prevention (e.g., knee and ankle injuries) [19]. Moreover, when appropriately conducted during rehabilitation, training of the SSC may also contribute to a shortened return to game time in youth and elite athletes [17, 20–29]. The risk of sustaining anterior cruciate ligament (ACL) injuries is particularly high in female athletes due to sex-specific jump-landing mechanisms (e.g., higher knee valgus in females) and hormonal differences (higher estrogen levels in females) causing ligamentous laxity [30]. Markovic and Mikulic [27] postulated that female handball athletes particularly benefit from reactive strength training because it lowers the risk of sustaining ACL injuries.

Taken together, the aims of this chapter are to describe performance-enhancing and injury-preventive effects of reactive strength training in youth athletes with a specific focus on handball.

In addition, the chapter will close with recommendations on how to implement effective reactive strength training protocols in youth handball.

37.2 What Is the Stretch-Shortening Cycle?

When performing exercises in the SSC (e.g., drop jumps), the trained muscles are initially pre-stretched during the braking phase and activated in a plyometric (i.e., eccentric) mode. During the subsequent push-off phase, the trained muscles powerfully contract and are activated in a myometric (i.e., concentric) mode. The terms "reactive strength training" and "plyometric training" are often used synonymously in the literature. However, this is not appropriate because the term plyometric training implies that plyometric (i.e., eccentric) muscle actions are performed only during training. Human movement in general (i.e., everyday and sport-specific activities) is often characterized by muscle actions taking place in the SSC. In fact, it has previously been reported that 95% of sport-related movements are conducted in the SSC [31]. In other words, a typical sport-specific movement in the SSC (e.g., countermovement jump) is initiated by a countermovement in opposite direction through rapid knee flexion (i.e., plyometric phase) that is immediately followed by an explosive upward movement of the leg extensors during the myometric phase prior to take off. Besides vertical jumping, the handball throw is another sport-specific movement that is initiated by a countermovement of the throwing arm (i.e., lengthening of the m. pectoralis and m. triceps brachii) which is immediately followed by a rapid shortening of these muscles to accelerate the handball in the direction of the target. This specific sequence of muscle activation produces an increase in total force output that has previously been denoted as the SSC [14]. More specifically, during a fast stretch of the muscle-tendon complex, energy is stored for a short period of time (<250 ms) in both the connective tissue and the tendons. If this stretch is followed by an immediate contraction of the same muscle-tendon complex within a time period of approximately 250 ms, the stored energy can be utilized during the subsequent myometric phase resulting in higher force output and better sport-specific performance (e.g., jumping, throwing) [15, 27, 32–42].

Most athletes and coaches intuitively know that a countermovement prior to the initiation of a sport-specific action results in better vertical/horizontal jump performance or throwing velocity, compared to an action without prior countermovement. Besides improved coupling of plyometric (i.e., eccentric) and myometric (i.e., concentric) muscle actions, better intermuscular coordination in terms of increased synergistic muscle activations and decreased muscle co-contractions has also been reported following reactive strength training [27]. Due to the underlying physiological responses, exercises in the SSC are highly demanding for the central nervous system and other physiological structures (e.g., muscle-tendon unit). Based on this premise, reactive strength training is considered a key training type that can be applied during all stages of long-term athlete development to promote physical development, to enhance physical fitness, and to prevent injuries [4, 43–45] (see Fig. 37.1). Faigenbaum and McFarland [46] recommended to start strength training as early as participants are able to accept directions and follow safety rules (age 7–8 years).

37.3 General Considerations Regarding the Training of the Stretch-Shortening Cycle in Young Athletes

Training of the SSC is highly demanding for the neuromuscular and the muscle-tendon system, and it affords high technical skills which is why this type of training should be conducted in a non-fatigued state. Two fundamental training principles ensure effectiveness and safety of SSC training: (1) always prioritize technical accuracy during training over training volume and intensity; (2) always prioritize health and safety issues over performance.

In order to meet these training principles, it is important that (young) athletes conduct reactive strength training with high attentiveness and in a non-fatigued state. In addition, a warm-up should be performed to adequately prepare the neuromuscular system and the muscle-tendon unit for the subsequent training stimuli [21, 47–49]. Reduced attentiveness and/or fatigue may result in impaired execution of reactive strength exercises. In this case, the training load should be significantly lowered, or training should be immediately terminated. Two reliable indicators for insufficient attentiveness and/or fatigue during exercise are prolonged ground contact times (>250 ms) and/or impaired lower limb alignment (knee valgus) during drop jumps [50]. More specifically, during reactive strength training, coaches should be aware of short ground contact times during jumping (<250 ms), heel clearance during landing, and proper lower limb alignment (no knee valgus) (Fig. 37.3c). Experienced coaches are often able to spot these inaccuracies during exercise execution without the use of technical support. Biomechanical testing apparatus (e.g., force plates, optoelectronic systems, motion-capturing systems) can assist in monitoring accurate performance. For instance, if the heel touches the ground during the braking phase of a drop jump, the force-time curve is characterized by an additional impact peak that occurs right before the active peak (Fig. 37.1).

Longer ground contact times (>250 ms) can be detected using force plates, contact mats, and/or optoelectronic systems [51]. It is possible to visualize lower limb malalignment by placing a camera in the athlete's frontal movement plane (see Fig. 37.2a, d, e).

Even though, different research groups were able to show that additional training loads and/or single leg jumps in the SSC are time-efficient means to improve performance [52, 53], it is recommended to avoid marked overload in youth for safety reasons. In fact, it has previously been purported that the systematic performance of athletic training results in nonuniform adaptations of muscles and tendons (i.e., muscle strength vs. tendon stiffness) in young athletes which increases the demand on the tendon (e.g., Achilles tendon,

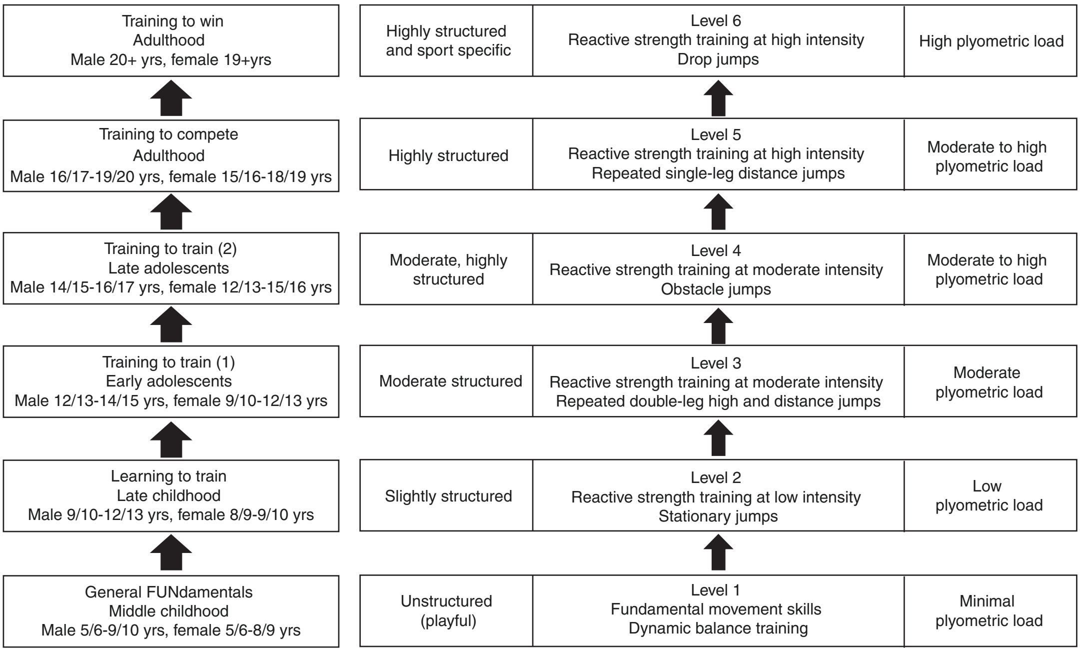

Fig. 37.2 Conceptual model for the implementation of reactive strength training during the stages of long-term athlete development according to sex and chronological age (Bompa and Buzzichelli [57]; Granacher et al. [45]; Lloyd et al. [50])

patellar tendon) and may result in an increased risk of sustaining tendon injuries [54].

Thus, adequate and safe SSC training protocols in youth should follow maturation, training experience, and sex-specific demands by focusing on movement velocity rather than high plyometric (i.e., eccentric) training loads [50, 55] (see Fig. 37.2).

Before the performance of a systematic training of the SSC at the high-performance training stage [56], different training types have to be gradually introduced over 2–4 years to avoid overuse injuries. In this regard, Bompa and Buzzichelli [57]; Lloyd, Oliver, and Meyers [50]; and Granacher et al. [45] recommended that a moderately structured training of the SSC should be applied up to the ages of 12–15 years for males and up to the ages of 9–13 years for females using moderate loads during exercises (e.g., max. 1 kg medicine ball) and moderate jump heights and distances (e.g., rope skipping, obstacle jumps, box jumps) (Fig. 37.2 and Table 37.2). It is recommended to continuously increase training intensity over the different stages until the high-performance training stage is reached (train to win). This can be realized by using extra loads, by increasing the drop height, and by applying single leg jumps or dynamic squats. Notably, before coaches decided to increase training intensity, it is crucial that exercises are performed with proper technique, for instance, in terms of lower limb alignment [45, 55]. In beginners starting with reactive strength training, coaches should be aware of an often encountered protective mechanism that is prevalent during drop jumps, that is, long ground contact times and thus “soft landing.” However, the efficient utilization of the stored energy during the plyometric phase is only possible with short ground contact times [58, 59]. Therefore, this SSC-specific performance characteristic should be taught right from the beginning.

In addition, Granacher et al. [45] introduced a conceptual model on how to implement different types of strength training during the stages of long-term athlete development. In their scoping review, these authors recommended to conduct balance training and reactive strength training (i.e., plyometric training) in the stages “learning to train,” “training to train,” and “training to compete.” This appears of high relevance, both from a performance-enhancing and an injury-preventive perspective. An efficient way of training balance and the SSC at the same time is to conduct reactive strength training on unstable surfaces. The underlying rationale for this approach is the principle of training specificity which denotes that training should mimic the demands of competition (e.g., slippery surfaces, tackles from opponents, etc.). To evaluate the effects of reactive strength training on unstable surfaces, Granacher and colleagues conducted a series of experiments in which they examined performance-enhancing effects following reactive strength training on unstable surfaces versus reactive strength training on stable surfaces in prepubertal and pubertal soccer and handball players [60–62]. Of note, irrespective of the examined age group and sport discipline, larger performance-enhancing effects (i.e., CMJ height) were found in the stable reactive strength training group compared to the unstable group. Given that no extra performance-enhancing effects of unstable reactive strength training were noted, subsequent studies investigated sequencing effects of balance and reactive strength training (i.e., plyometric training). For instance, Chaouachi et al. [63] studied whether a blocked balance training that is conducted prior to reactive strength training may induce larger performance-enhancing effects compared to the opposite sequencing order. These authors found that 4 weeks of balance training executed prior to 4 weeks of reactive strength training as opposed to a group that exercised in the reversed sequencing order resulted in larger performance-enhancing effects in components of physical fitness in prepubertal male soccer players. Notably, similar findings were previously reported by Bruhn and colleagues [64] who examined sequencing effects of balance training with traditional strength training. In another study, Chaouachi et al. [65] looked at the effects of the within session sequence of balance and reactive strength exercises (i.e., plyometric exercises) on measures of physical fitness. Twenty-six male adolescent soccer players (13.9 ± 0.3 years) participated in an 8-week training program that either alternated individual balance (e.g., exercises on unstable surfaces) and reactive strength exercises (e.g., jumps, hops, rebounds) or performed a block of balance exercises (30 min) prior to a block of reactive strength exercises (30 min) within each training session. These authors reported no statistically significant between-group differences in physical fitness performance over time which is why they concluded that the within session sequence of balance and plyometric exercises does not affect training-induced performance outcomes. Taken together, it seems that the time-efficient combination of balance and reactive strength training on unstable surfaces does not have an additional performance-enhancing effect on components of physical fitness. Whether this specific type of training is suitable and effective as an injury-preventive program in youth athletes remains to be clarified in future studies. With regard to the sequencing effects of balance and reactive strength training, it is recommended to conduct a block (4 weeks) of balance training prior to 4 weeks of reactive strength training. Finally, it seems that the within session sequence of balance and reactive strength exercises appears not to additionally affect performance-enhancing effects.

The previously described conceptual model of Granacher and colleagues [45] on the implementation of strength training during the different stages of long-term athlete development contains not only balance and reactive strength training (i.e., plyometric training) but also heavy resistance strength training and free weight training particularly during the later stages (i.e., “training to train,” “training to compete,” “training to win”) of long-term athlete development.

In two recent systematic reviews and meta-analyses, Lesinski et al. [66] and Behm et al. [67] examined (1) the effects of strength training (i.e., machine-based training, free weight training, functional training, reactive strength training [i.e., plyometric training], complex training) in youth athletes on measures of physical fitness and (2) contrasted the effects of strength versus power training (i.e., includes reactive strength training and high-velocity strength training) on components of physical fitness in child and adolescent athletes and their untrained peers.

Irrespective of age and sex, Lesinski et al. [66] observed moderate effects of strength training on measures of muscular strength (e.g., 1RM) and muscular power (e.g., CMJ height) and small effects on muscular endurance (e.g., prone bridge test) and sport performance (e.g., throwing velocity) in youth athletes. A sub-analysis revealed larger improvements in child compared to adolescent athletes in relative muscle strength. Moreover, girls showed larger enhancements in sport-specific performance compared to boys. In terms of training type, the study of Lesinski et al. [66] revealed the largest effects of free weight training on measures of muscle strength as compared to, for instance, machine-based training, functional training, or reactive strength training. Of note, complex training which combines heavy resistance strength exercises with reactive strength exercises in an alternated or blocked form showed the largest effects on sport-specific performance. Finally, in an attempt to aggregate dose-response relationships following strength training in adolescent athletes, Lesinski et al. [66] observed the largest effects for muscle strength improvements following a long (>23 weeks) and intense strength training protocol (80–89% 1RM) (see Table 37.1).

The recent meta-analysis of Behm and colleagues [67] proved that, irrespective of age and sex, power training (i.e., high-velocity strength training and reactive strength training) was more effective than traditional strength training for improving youth jump height. For sprint

Table 37.1 Effective dose-response relationships for strength training in adolescent athletes to improve muscular strength (Lesinski et al. [66])

Effective training modalities
• Training duration: > 23 weeks
• Training intensity: 80–89% of the one-repetition maximum
• Training frequency: 2–3 sessions/week
• Muscle actions: Myometric and plyometric
• Sets: 5
• Repetitions: 6–8
• Rest between sets: 3–4 min

measures, strength training was more effective than power training with youth. Furthermore, strength training exhibited consistently large magnitude changes to lower body strength measures, which contrasted with the generally trivial, small, and moderate magnitude training improvements of power training upon lower body strength, sprint, and jump measures, respectively. In general, the sub-analyses indicated larger training-related effects in untrained compared to trained subjects and in children compared to adolescents. Based on the results of their study, the authors concluded that strength training should be incorporated prior to power training (i.e., high-velocity strength training and reactive strength training) in order to establish an adequate foundation of strength for power training activities.

37.4 Effects of Reactive Strength Training on Lowering Young Athletes' Injury Risk

The combined effects of growth, maturation, and strength training result in increased levels of muscle strength in adolescent athletes which will result in higher strains in the tendinous tissue, making it more prone to injury [68]. This is reflected in high tendinopathy prevalence rates in adolescent athletes from sports like handball, soccer, volleyball, basketball, and track and field. In the study of Gisslèn et al. [69], 11% of the patellar tendons of Swedish elite junior volleyball players aged 15–19 had a diagnosis of jumper's knees. In the untrained age- and sex-matched control group, no individual had a clinical diagnosis of jumper's knee. It has previously been speculated that a major contributing factor for the increased prevalence of tendon injuries in adolescent elite athletes could be the imbalanced adaptation of muscle and tendon in response to strength training [70]. The adaptation process of tendons is based on mechanical load imposed on the physiological structures [71, 72]. In addition, limited blood supplies [73] and low metabolic rate in tendon compared to muscle tissue [74] may result in nonuniform and tissue-specific adaptations. In other words, muscle and tendinous tissue appears to adapt to different mechanical loads. While Lesinski et al. [66] reported that strength training intensities of 80–89% of the 1RM are effective to induce adaptive processes in muscle strength (see Table 37.1), Mersmann et al. [75] postulated that an effective strength training protocol to induce adaptive processes in tendinous tissue is characterized by intensities >90% of the 1RM in plyometric (i.e., eccentric) and/or isometric mode with times under tension of 3–6 s for the single repetition. Based on these findings, it appears plausible to argue that tissue-specific dose-response relationships exist following strength training in adolescent athletes. Therefore, from an injury-preventive perspective, it is recommended to always combine reactive strength training with a strength training protocol directed at tendon-specific adaptations to lower the risk of sustaining injuries of the Achilles and/or patellar tendon in youth athletes participating in high-impact sports like handball, volleyball, soccer, and basketball. Tendon-specific strength training with the goal to reduce imbalances in muscle-tendon adaptation is time efficient and can be included in the warm-up program of sport-specific and/or athletic training sessions [76].

Moreover, Myklebust and colleagues [77] examined the effects of a neuromuscular training program consisting of balance (e.g., one-legged stance on balance pads) and reactive strength exercises with the goal to improve awareness and knee control during standing, cutting, jumping, and landing on the incidence of ACL injuries in female handball players from the top three Norwegian divisions. Between 52 and 60 teams were followed over one control and two intervention seasons with 850 to 942 players participating in this study. Over the course of the two monitored intervention seasons, the participating handball teams conducted the intervention program in the preparation period of the handball season over a duration of 5–7 weeks with three training sessions per week, each lasting 15 min. During the in-season period, training volume was lowered to one session per week lasting 15 min. The team coaches were responsible for carrying out the program, and they also recorded the total number of ACL injuries. During the control season, 29 ACL injuries were reported, while during

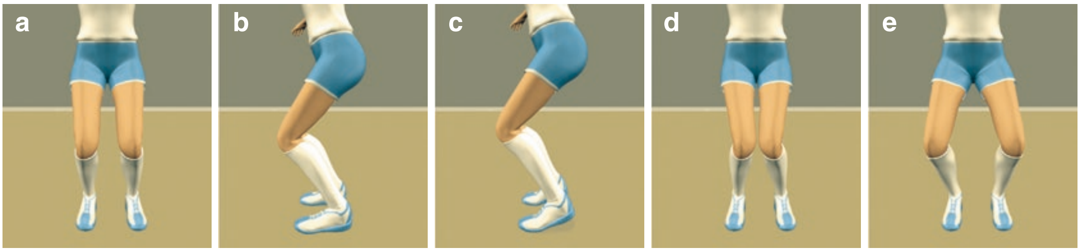

Fig. 37.3 Different forms of lower limb alignment during landing in sagittal (**b**, **c**) and frontal plane (**a**, **d**, **e**). (**a**, **b**) proper lower limb alignment during landing; (**c**) proper lower limb during drop jumps; (**d**) lower limb malalignment (knee valgus); (**e**) lower limb malalignment (knee varus) (Büsch, Marschall, Goebel, Kromer, & Granacher, 2016, p. 43). Reprinted by permission from Büsch, Marschall, Goebel, Kromer, Granacher, 2016, Differenziertes Reaktivkrafttraining für Handballer. Teil 1, p. 39, Philippka-Verlag, Germany

the first intervention season, 23 injuries were recorded (13% lower odds ratio), and finally during the second intervention season, 17 ACL injuries were registered (36% lower odds ratio). The corresponding total injury incidence was 0.14 ± 0.05 per 1000 player hours (control season), 0.13 ± 0.06 per 1000 player hours (first intervention season), and 0.09 ± 0.06 per 1000 player hours (second intervention season). Taken together, the study of Myklebust et al. [78] clearly showed that it is possible to prevent ACL injuries in an at-risk population of female handball players with combined balance and reactive strength exercises.

37.5 Landing Patterns of Lower Limb Reactive Strength Exercises

Figure 37.3a, b demonstrates appropriate lower limb alignment as well as the recommended knee and ankle position during a soft (energy absorbing) landing task. Knee and feet should be held in parallel position and point frontward. Ankle and knee joint continuously flex during landing with the heel showing a soft and smooth touchdown to the ground (applicable for intensity levels 3–5 in Fig. 37.2). Figure 37.3c illustrates the touchdown of the feet performing a drop jump in the SSC. In this case, the heel is not supposed to touch the ground during the braking phase (energy utilizing landing) of the landing; otherwise the elastic energy will be wasted.

The importance of a systematic and thorough conditioning program before the performance of reactive strength training is supported in Fig. 37.3d, e. The lack of technical skills together with inappropriate inter- and intramuscular coordination and deficits in lower limb muscle strength results in lower limb malalignment and an increased risk of sustaining injuries. Figure 37.3d illustrates a valgus position of the knee combined with an internal rotation that should be avoided at any time during training and competition. Figure 37.3e highlights an unfavorable/disadvantageous varus knee position, combined with an external rotation. These knee positions are frequently combined with an over-pronation or oversupination of the ankle joint resulting in an increased injury risk. Therefore, lower limb knee and foot alignment have to be controlled by physicians, therapists, and/or coaches. With simple feedback from cell phone video cameras, lower limb alignment can be recorded and presented to athletes and coaches. If a lower limb malalignment is detected, the respective athlete should consult a specialist to correct the improper landing patterns.

37.6 Specific Considerations for the Performance of Reactive Strength Exercises in Young Athletes

In addition to the rather general guidelines summarized in Fig. 37.2, specific recommendations on the implementation of reactive strength

Table 37.2 Exemplified lower limb exercises for improving reactive strength exercises conducted in the stretch-shortening cycle (Bompa and Buzzichelli [57]; Büsch et al. [84]; Granacher et al. [45]; Lloyd et al. [50])

Intensity level	Classification	Exercise	Repetitions × sets	Rest time (min.)
#		Drop jumps (>70 cm, >250 ms ground contact time	1–10 × 2–6	4–8
		Single leg or hydraulic jump	20–40 m × 2–4	3–5
6	High intensity	Drop jumps (40–60 cm, <250 ms ground contact time)	3–10 × 2–6	3–6
5		Single leg or hydraulic jump	5–30 m × 2–6	3–5
4	Moderate intensity	Hurdle/obstacle jump (60 cm)	3–12 × 2–6	3–5
		Squats at maximum movement velocity (possibly with jump), American- or power Kettlebell swing	3–6 × 2–6	3–4
3		Hurdle/obstacle jump (30–60 cm)	6–20 × 2–6	3–5
		Box jumps, landing on the box (60–110 cm)	3–15 × 2–6	3–5
		Kettlebell swing	10–30 × 7–15	2–5
2	Low intensity	Hurdle/obstacle jump (<30 cm)	6–20 × 3–6	2–3
		Double leg hops/bounds, skipping	10–30 × 7–15	1–2
		Rope skipping	15–50 × 2–6	1–3

The exemplified training exercises and modalities on the highest intensity level are expert based. Those exercises which focus primarily on plyometric muscle actions should not be applied in young athletes

exercises, such as exercise selection, training frequency, sequencing order, training load and repetitions, and training volume, are displayed in Table 37.2. These parameters, as well as the technical skills and movement quality of the respective exercises, are crucial elements for a properly conducted reactive strength training program. Athletes with little or no experience with reactive strength exercises should perform 1–3 sets (duration of one set approximately 10 s) with 6–10 repetitions per set conducted twice per week with at least a 48-h rest time between training sessions [21, 38, 44, 45, 50, 79, 80]. Accordingly, this results in a training volume of 50–60 jumps during a single training session which can progress to 80–150 jumps depending on age and training expertise of the individual athlete over the course of an 8–12-week training period [38, 50, 79, 81]. Occasionally, it is recommended to extend a reactive strength training period from 24 weeks up to 12 months [27, 56, 82]. It appears that reactive strength training with the goal to improve throwing performance requires less training volume. More specifically, it seems that during a single training session, 30–60 throws in the SSC are sufficient to induce performance enhancements [15]. Moreover, 3–4 exercises (e.g., different hops and skips), with 2–4 sets and 6–12 repetitions, are recommended during a 10–25 min training session [81]. If training frequency amounts to one session of reactive strength training per week only, training duration should be extended to approximately 14 weeks. During the first weeks of training, 16 repetitions of jump exercises should be conducted and progressively increased to 60 repetitions at the end of the 14-week training period [79]. To avoid fatigue during training, rest periods should be long enough so that athletes are able to fully recover and conduct the exercises with proper movement technique. This may in fact result in a longer rest time than the previously suggested 2–4 min so a 5 min rest is nothing uncommon. These rather long rest periods can be used time efficiently by performing balance exercises or technical/tactical exercises at low intensities particularly for the stressed physiological structures during training. It has previously been reported that circuit training is an appropriate means to organize reactive strength training, whereby one coach supervises four to five athletes per group. During circuit training, athletes move from one exercise to the next so that training time can be used efficiently. With advanced training experience, training intensity can be increased in accordance with the recommendations as presented in Table 37.2. Of note, it is important to constantly monitor the increased drop height as prolonged ground contact times are indicative of an effective SSC. In this context, it is recommended to conduct less training volume at higher movement quality [58, 82].

37.7 Conclusions

Reactive strength training (i.e., training of the SSC) has proven to be an effective means for performance enhancement and injury prevention in handball and other ball games (e.g., soccer, basketball). A systematic and progressive training approach is needed during all stages of long-term athlete development to induce adaptive changes following reactive strength training [29, 47, 50, 55, 83, 84] and to increase the likelihood of transferring a talented young player into an elite athlete. During long-term athlete development, training volume and intensity should always be in accordance with biological maturity and training experience (Fig. 37.2 and Table 37.2). In addition, this book chapter points out that, prior to the application of a long-term reactive strength training, balance training as well as a specific strength training for tendon adaptations should be conducted to improve performance and to resist injuries. Findings from studies on reactive strength training predominately focus on jump exercises during the SSC (Table 37.2). However, the scientific evidence of reactive strength training effects on throwing is comparably limited. Exercises with medicine balls or modified push-ups, for example, can be implemented in handball training. The choice of exercises and the classification of the intensity levels of upper extremities can only be considered in analogy to the parameters of lower extremity parameters. However, a handball-specific selection of upper body training of the stretch-shortening cycle exercises has been suggested [28, 42, 83, 84]. A differentiation between genders is not advised, justified by similar effects of training exercises when SSC is applied to either gender. The related load adaptations account predominantly to the training experience, and only subsequently to the level of performance of the athlete [38].

37.8 Reactive Strength Training Guidelines for Young Athletes and Coaches

The guidelines of Tables 37.3, 37.4 and 37.5 summarize the empiric findings presented in the above paragraphs of this book contribution and

Table 37.3 General guidelines for athletes to perform reactive strength exercises

A 1	Always exercise with high attentiveness during training. Immediately stop training if you are unable to concentrate on proper movement execution
A 2	Always exercise with the highest level of movement quality (correct technique). Stop training as soon as you start to feel fatigued
A 3	If you are not experienced with reactive strength exercises, conduct training only if proper supervision is guaranteed

Table 37.4 General guidelines for coaches to perform reactive strength exercises

T 1	Initiate a slightly structured reactive strength training for your athletes at the age of 8/9 (female) and 9/10 (male) years and start with a moderately structured reactive strength training program at the age of 9/10 (female) and 12/13 (male) years
T 2	Always combine reactive strength training with a permanently applied (maximum) strength training program
T 3	Reactive strength training at the high-performance level needs proper preparation for 2–4 years
T 4	Consult the information provided in Fig. 37.2 and Table 37.2 to select proper exercises and intensity levels
T 5	Adjust the intensity level gradually with training experience and performance level – Not toward the biological age of the athlete
T 6	If movement quality during exercises suffers and ground or ball contacts of the foot occur, stop the training
T 7	During the performance of drop jumps, always focus on the athlete's heels. They should not touch the ground
T 8	Do not apply additional loads in training with novice athletes
T 9	Monitor the knee and foot for proper lower limb alignment during landing – always correct knee varus and/or valgus alignment and supinated and/or pronated foot alignment
T 10	If athletes are fatigued or distracted during training, immediately stop the training

Table 37.5 Specific guidelines for athletes and coaches to perform reactive strength exercises

S 1	Start a reactive strength training program with a 4–8-week familiarization period
S 2	Start with an 8–12-week balance training program, prior to the first reactive strength training program
S 3	Accompany the reactive strength training with a specific strength training that focuses on tendon adaptation. Tendons need more time to adapt to training stimuli compared to muscles
S 4	Always conduct a 5–10 min warm-up program prior to reactive strength training
S 5	Always wear proper sport shoes while exercising

transform those into advices for athletes and coaches. The following guidelines differentiate between general and specific ones. The general guidelines apply always in preparation or during a reactive strength training. Specific guidelines are adjustable to individual training situations and circumstances before and during a reactive strength training exercise program.

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Part V

Special Considerations

38

The Female Handball Player

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Abbreviations

ACL	Anterior cruciate ligament
DE	Disordered eating
EA	Energy availability
ED	Eating disorders
FP	Follicular phase
GH	Growth hormone
GLP-1	Glucagon-like peptide-1
GnRH	Gonadotropin-releasing hormone
GWG	Gestational weight gain
H:Q	Hamstrings:quadriceps
IGF-1	Insulin-like growth factor
LH	Luteinizing hormone
LP	Luteal phase
MC	Menstrual cycle
OC	Oral contraceptives
P1CP	Carboxy-terminal propeptide of type I procollagen in serum
PYY	Peptide YY
RFD	Rate of force development
RMR	Resting metabolic rate
RR	Relative risk
T3	Triiodothyronine

38.1 Introduction

Team handball is a physically demanding sport where success is determined by a complex interplay between many factors; muscle strength and power, aerobic and anaerobic capacities, technical

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and tactical skills, as well as psychological factors. In addition, endocrinological factors may influence these parameters [1]. The latter has among athletes, coaches, as well as researchers triggered speculations about the influence of female hormones on athletic performance. The localization of the estrogen receptors (ERα and ERβ) and progesterone receptor in skeletal muscle tissue suggests a functional role of the female hormones within the skeletal muscle. This has stimulated the research within the area in the last couple of decades. Still there are many unanswered questions. This chapter is aiming at giving the reader a brief insight into the present knowledge about the influence of female hormones on muscle strength and power, tendon and ligament properties, as well as anaerobic and aerobic performance. There will be a specific focus on biomechanical and neuromuscular gender differences in perspective to the five times higher risk of sustaining an anterior cruciate ligament (ACL) rupture in female compared to male handball players. Finally, dietary consideration in regard to the female athletes will be discussed.

38.2 Hormonal Fluctuations During the Menstrual Cycle and Oral Contraceptive Pill Cycle

In normal menstruating women, the female hormones estradiol and progesterone fluctuates in a well-defined predictable pattern during the menstrual cycle (MC) (Fig. 38.1). The cycle length is on average 28 days (range 20–45 days) and is split up in phases depending on the varying concentration of estradiol and progesterone.

Estradiol and progesterone are both at their lowest levels during menses at the beginning of the MC (days 1–6). Estradiol reaches its peak concentration in the late follicular phase (FP) (days 12–14) around the time of ovulation, where progesterone only gradually begins to rise. In the luteal phase (LP), a second lower rise (days 20–24) in estradiol is experienced. Progesterone is at its highest level during LP and peaks around days 19–24. Thereafter a sharp decline in progesterone takes place within days.

Use of oral contraceptives (OCs) varies between countries, but seems to correspond to the general female population [2]. The primary reason for using OC is contraception, but other reasons include dysmenorrhea, the possibility to control and manipulate timing of menses, and for reducing symptoms experienced during a normal menstrual cycle such as abdominal and lower back pain and acne. OC usually contains between 15 and 35 μg ethinyl estradiol (EE). Depending on the type of OC, the pills also contain different types of progestins/gestagens, which bind to the progesterone receptor with differential affinities. Daily ingestion of an OC pill leads to short-lived rises in EE and progestins in the hours after ingestion, but overall OCs provides a steady-state hormonal level during the OC consumption phase, while the endogenous

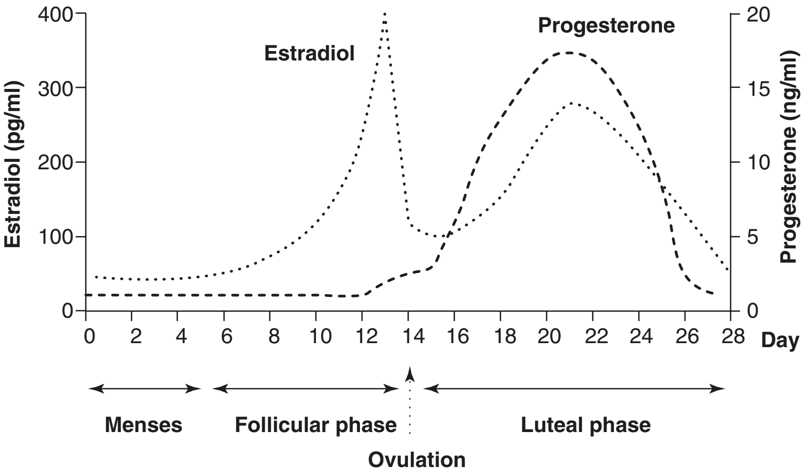

Fig. 38.1 Hormonal changes during the menstrual cycle. Overview over the hormonal changes in estradiol and progesterone during the menstrual cycle in young women who do not use oral contraceptives

female hormones are being suppressed. During the OC withdrawal phase, small rises in endogenous hormones are observed. The most commonly used OCs are monophasic OCs containing constant doses of EE and progestin during the entire pill cycle, although the progestin may differ depending on the generation of OC. The most prevalent type of OC is second-generation OCs, which contain either levonorgestrel or norgestimate, but also third-generation OCs containing desogestrel, or gestodene and fourth-generation OCs containing either dienogest or drospirenone are used. The androgenity of the OC differs depending on the type of progestin and the concentration of both EE and progestin. The second-generation OCs are reported to be more androgenic than third-generation OCs, but the specific knowledge in regard to the anabolic potential of the different types of OC is only elucidated to a very limited extent. It is important to realize that there is large intersubject variability but also intrasubject variability in pharmacokinetic parameters and circulating levels of EE and the progestins after OC administration. In two women, who ingested the same type and dose of OC, a fivefold difference in serum levels of a progestin was detected. Therefore, female athletes may react different on OC administration depending not only on the type of OC but also unknown individual factors.

38.3 Female Muscle Strength and Power

38.3.1 Muscle Strength

The natural fluctuations of hormones during the menstrual cycle have fostered the hypothesis that muscle strength of female athlete changes during the menstrual cycle leading to a better performance at specific time points. Observations of variable expression of the ERα and progesterone receptor genes and proteins throughout the menstrual cycle supports this. Nevertheless, studies in this area are in general inadequate. Some early studies have found difference in isometric strength at a certain time point during the menstrual cycle, but the optimal time point differed between studies, reflecting the different methodologies, muscle groups, and group of females investigated in each [3]. Most studies found no difference in muscle strength performance between the different phases of the menstrual cycle [3]. Nevertheless, some studies indicate that there might be an increase in muscle strength around the time of ovulation, when estradiol is high and progesterone levels are still low [4, 5]. Also in regard to the effect of the use of OC on muscle strength and adaptation to strength training, there is limited evidence [3, 6]. Some studies have indicated that particularly the use of triphasic OCs may improve muscle strength around the time of ovulation. However, only about 2–5% of women use triphasic OCs. Research on monophasic OCs in both untrained women and athletes found no difference in maximal strength during an OC cycle [6]. Still further investigations are needed to clarify the specific influence of different types of OC on muscle strength performance.

38.3.2 Power and High-Intensity Performance Measures

It has been proposed that the carbohydrate metabolism and buffering capacity might be altered during LP to decrease lactate levels, which could hypothetically improve anaerobic capacity. The research on anaerobic capacity – defined as the ability to produce short-term high-intensity efforts (sprints, jumps, or throws) – throughout the MC or OC cycle is sparse. There is no consensus as to whether a greater anaerobic capacity and peak power is found during the LP. Some studies have observed improved performance during the FP compared to the LP and ovulation; however, most studies found no difference [1, 3]. In addition, active women seem to be less likely to be influenced by time of the MC compared to untrained women.

During the OC withdrawal phase, compared to the OC consumption phase, one study on rowers showed improvements in anaerobic power (10 seconds all-out rowing) [7], while another four studies found no difference in power (cycling, jumping, and stair-climbing performance) throughout the OC cycle [8, 9]. One of these showed even a decreased reactive strength during the late withdrawal phase measured by box jumps from 30 or 45 cm height [10]. The mixed monophasic OCs used in this study—with progestins ranging from the antiandrogenic cyproterone to the high androgenic levonorgestrel—may have influenced the overall hormone milieu and thereby the study conclusions. In general, the differential findings among studies may be related to different test parameters and use of differential types of OC. Therefore, more well-controlled studies are needed to clarify the effect of the individual types of OC on muscle power in specific handball relevant tests.

38.3.3 Muscle Damage and Muscle Strength Recovery

For athletes competing on consecutive days during tournament events, a fast recovery of muscle function after muscle-damaging exercise is crucial. Cross-sectional data indicate that estradiol reduces muscle damage and shortens the time for functional recovery following non-weight-bearing muscle-damaging eccentric exercise when comparing women and men [11]. However, part of the explanation for observed reduced muscle damage might be caused by reduced tendon stiffness in women, which may reduce the impact of the contractions during maximal effort on the muscle tissue. In weight-bearing situations, greater muscle damage has been observed in women compared to men, which may be explained by relative greater fat mass and thereby load during jumping and running. Therefore, the protective effect of estradiol might be a mechanistic way the body tries to reduce the drawbacks of relative greater fat mass in women compared to men. Collectively, supporting evidence suggests that estradiol helps to reduce muscle damage and that the effect may be through an increased activation of the muscle stem cells. Contrary, the use of OC seems to reduce the protective effect since OC users experience greater muscle damage and reduced recovery in muscle function compared to nonusers. Again, part of the explanation might be that tendon stiffness has been observed to be higher and knee joint laxity reduced in OC users, which will enhance the impact of maximal muscle contractions on the contractile muscle tissue.

38.3.4 Adaptations to Strength Training

Skeletal muscle size and growth is dependent on the net balance between the muscle protein synthesis rate and the muscle protein degradation rate. Animal data indicates that estradiol stimulates, whereas progesterone reduces muscle protein synthesis. When both hormones are present in high concentrations, they may counteract each other. However, we did not observe any differences in the myofibrillar protein synthesis rate in eight young females tested 2–3 days after the onset of menses (the FP) and seven females tested in the LP 4 days after a positive ovulation test. However, if a high estradiol to progesterone ratio enhance muscle protein synthesis, as suggested by animal data, it would have been ideal to include measurements in the late FP around ovulation. Still, a study in postmenopausal women reported no stimulating effect of transdermal estradiol administration on muscle protein synthesis, whereas progesterone enhanced muscle protein synthesis rate. The latter study did not test the interaction between the stimulating effect of resistance exercise and administration of female hormones on muscle protein synthesis rate. Furthermore, it should be emphasized that the net change in muscle mass also is affected by changes in muscle protein degradation rate. No human studies have reported results on muscle protein degradation rate in response to administration of female hormones.

A couple of studies have aimed at elucidating whether the anabolic effect of resistance training on muscle mass and strength is influenced by the hormonal fluctuations during the menstrual cycle. Performing resistance training every second day in the FP and once per week during the LP instead of equally spread during the menstrual cycle led to greater improvements in strength [12]. Nevertheless, the latter findings may be explained by a difference in timing of the training sessions instead of and an effect of female hormonal fluctuations between phases. Also, a recent study by Wikström-Frisén and colleagues observed greater improvements in muscle strength and muscle mass following 4 months strength training in young women, who performed intensified resistance exercise training (five times per week) during the FP combined with once per week during the LP compared with young women performing intensified resistance exercise training in the LP and once per week during the FP [13]. These studies may suggest that the anabolic benefit of resistance training is enhanced if resistance training is performed when the estradiol to progesterone ratio is high. Nevertheless, in the latter study, a mix of OC users and nonusers were included [13], which may have affected the results.

The use of OC may also influence the adaptations to strength training. We have observed a lower myofibrillar protein synthesis rate in users of third-generation OCs (ethinyl estradiol and gestogen) compared with nonusers of OCs, which was not observed when nonusers were compared to users of second-generation OCs (ethinyl estradiol and norgestimate). These observations indicate that progestins have differential effects on myofibrillar protein synthesis rate. This might be related to differential potency and androgenicity of the progestins and the influence of the different types of progestins on the endogenous levels and availability of sex hormones (e.g., free testosterone and sex hormone-binding globulin). The effect of OC on myofibrillar protein breakdown rate is not clarified, but a couple of studies have investigated the anabolic effect of regular resistance training on muscle mass and strength in OC users. Following 16 weeks of strength training, no difference was observed in muscle strength gain in collegiate women softball and water polo players, who were non users or users of OC. However, the participants used a mix of different types of OC, which might have blurred the results. since several of the OC users used monophasic OC with no variations in synthetic hormones during the 21 days pill period. The abovementioned study by Wikström-Frisén included both non users and OC users, and the enhanced benefit of training on muscle strength and muscle mass observed seemed to be largely driven by the OC users in the early pill cycle [13].

Collectively, there is some evidence for a positive effect of intensified training during the FP and also evidence for an influence of OC on myofibrillar protein synthesis rate possibly leading to increase muscle gain. Still, future studies are needed to elucidate the individual effect of different types of OC on the anabolic effect of resistance training in athletes.

38.4 Aerobic and Metabolic Adaptations During the Menstrual Cycle

Maximal oxygen consumption, a main determinant of maximal aerobic performance, is influenced by several factors that may be affected by fluctuations in estradiol and progesterone during the menstrual cycle. These factors include substrate availability and utilization, heart rate, body temperature, hematocrit, and blood lactate [14].

38.4.1 Influence of the Menstrual Cycle on Substrate Metabolism

Availability and utilization of glucose and free fatty acids have implications for aerobic performance by affecting the onset of lactate accumulation and glycogen depletion. However, studies investigating substrate metabolism during exercise across the MC are conflicting. Some studies reported enhanced lipid metabolism during the mid-LP, and others reported no change across the MC [3, 6]. Studies have also revealed that exercise-induced blood lactate concentrations are highest in the mid-FP and lowest during the mid-LP. The suggested enhanced fat utilization during submaximal aerobic exercise in the LP suggests a potential sparing of glycogen storage. This could ultimately result in improved prolonged exercise performance. However, research studies are contradictory, which may be related to their differential study design (differences in exercise intensity and duration, dietary control and fitness status of the subjects). These circumstances make it difficult to establish a causal link between estradiol and progesterone fluctuations and substrate metabolism, blood lactate, or exercise performance.

38.4.2 Body Weight

Increased body weight and a “bloated feeling” is often reported around menses. The rapid decline in progesterone around menses results in excess water and electrolyte retention via a complex mechanism in the kidneys increasing body weight by up to 2 kg. This was evident in a 1-year prospective study including 62 women, observing a peak in fluid retention scores on the first day of menstrual flow [15]. An increased body weight may negatively impact performance in handball-related activities such as jumping, landing, and running. An increase in body weight may increase muscle damage in weight-bearing sports in general. Yet, research within this area is still limited and conflicting.

38.4.3 Red Blood Cells

The delivery of oxygen to exercising skeletal muscles facilitated by oxygen transport in red blood cells is one of the key determinants of maximal aerobic exercise capacity. Plasma volume has been shown to be highest around the day of ovulation, followed by a decrease in the early LP and an increase in the mid- and late-LP. Along these lines, highest hematocrit and hemoglobin concentration was found to coincide with the lowest plasma volume around days 15–19 of the MC. This could potentially affect maximal oxygen uptake. However, most evidence still suggests that the oxygen-carrying capabilities of the blood are not affected by the MC [16].

38.4.4 Blood Loss

Blood loss during menstruation could, in theory, affect maximal oxygen uptake. On average, the blood loss in women aged 15–50 years is ~40 mL (range 10–90 mL), with only ~10% of menstruating women losing more than 80 mL [16]. This is well below a level that would result in detectable reductions in maximal performance. Along these lines, most studies report no MC-related changes in heart rate, neither at rest nor during exercise, indicating that potential changes in blood volume and composition have no impact on hemodynamics.

38.4.5 Body Temperature

Basal body temperature increases by 0.3–0.5°C during the LP, which is likely related to an increase or shift in thermoregulatory set point. Increased body temperature is also evident during exercise, and thus, exercise performance may be limited during prolonged exercise in the heat in the LP [17].

38.4.6 Effects of Oral Contraceptive on Aerobic Adaptations to Exercise Training

Studies on the effect of OC on aerobic adaptations to exercise training are sparse, and results should be viewed with care. However, the first line of evidence suggests that OCs dampen the response to aerobic exercise training in terms of maximal oxygen uptake. This is in line with studies reporting OCs to reduce maximal exercise capacity, aerobic capacity, and the physiological response to acute exercise. Impaired aerobic training adaptations are also correlated to impaired improvements in cardiac output, suggesting that OCs may interfere with either blood volume or stroke volume [18].

38.4.7 Summary

In summary, current evidence suggests that hormonal fluctuations during the MC generally have little impact on aerobic exercise performance, but substrate metabolism may be altered during the LP.

From an athlete or coach’ perspective, all of the abovementioned factors should be taken into account during performance testing. There is a great interindividual variation in how the varying hormone levels affect the athlete’s body in terms of metabolism, body weight, blood composition, and body temperature. Therefore it is advised to do repeated testing of maximal performance on the same day in the menstrual cycle to isolate changes in performance from the variation induced by hormonal fluctuations during the MC/OC pill cycle. Finally, evidence suggests that OC may blunt some of the positive adaptions to aerobic exercise training. From an aerobic performance perspective, available evidence suggests that contraceptives other than OC may be advisable at least for the "in field" handball players who are challenged in regard to aerobic capacity. However, more studies within the area are needed to draw any final conclusions.

38.5 Tendon and Ligaments: Influence on ACL Injury Risk

Anterior cruciate ligament (ACL) injuries can be devastating and even career ending for some athletes. The highest incidence of noncontact ACL injury in ball sports is observed in team handball [19]. Female handball players are particularly at risk of sustaining this serious knee injury. Myklebust et al. (1998) found a five times higher risk of sustaining an ACL injury in female handball players compared to their male counterparts [20]. In addition, it has been documented that young female team handball players are the most susceptible to sustain this type of injury [21, 22]. Thus, being a female handball player defines you as a high-risk athlete of sustaining an ACL injury. The underlying mechanisms for this gender discrepancy have been extensively examined during the past decades. Anatomical differences may be part of the explanation, but gender differences in modifiable risk factors such as muscle strength and biomechanical and neuromuscular properties during sports-relevant movements where ACL injuries occur may also play an explanatory role (for discussion of these risk factors, see Sect. 38.6 in this chapter). Finally, the focus of this section will be the influence of female hormones on tendon and ligament structure and biomechanical properties, which not only may influence injury risk, but also athletic performance.

38.5.1 Effect of Endogenous Female Hormones on Tendon Structure and Biomechanical Properties

Tendon and ligament biomechanical properties seem to be different in women compared to men [23]. Tendon fascicles from women rupture at a lower load compared to fascicles from men. In vivo measurement of tendon stiffness is lower in women compared to men during maximal isometric loading. In addition, cross-sectional data indicate that the hypertrophic effect of regular training on tendon size is reduced in women (Fig. 38.2).

Among females, the risk of sustaining an ACL injury seems to variate during the MC and be lower in OC users than in non users [24]. A systematic review and meta-analysis reported that in four out of the included five studies, ACL injury risk in nonusers of OC was lowest during LP and highest in the late FP around ovulation [24]. In line with this, knee ligament laxity has been reported to be increased around ovulation in the late FP compared to early FP during menses. In four of five studies, which had collected blood for analysis of female hormones, the highest degree of knee ligament laxity was observed when

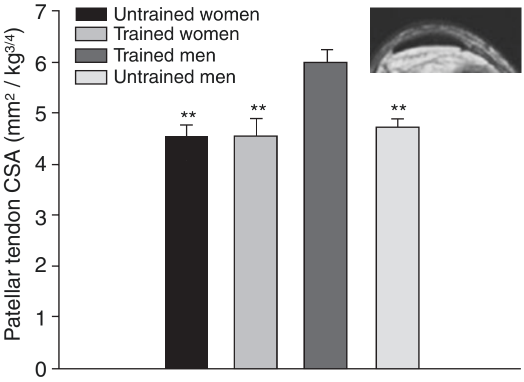

Fig. 38.2 Patellar tendon cross-sectional area in trained and untrained runners. The magnetic resonance imaging determined patellar tendon cross-sectional area (CSA) for trained and untrained men and women normalized to body mass. Trained men had a greater CSA than untrained men ($P < 0.01$); however, note that trained women had a similar CSA compared with untrained women [23]. Copyright 2007 John Wiley and Sons. Used with permission

estradiol concentration was highest in the late FP. This supports the idea that estradiol is playing a significant role on ligament properties. Tendon and ligament biomechanical structural properties are determined by the cross-sectional area and the collagen fibril characteristic. In addition, intra- and intermolecular enzymatic and nonenzymatic cross-links within the collagen structure enhance tissue stiffness. In perspective to the observed higher ACL rupture risk around ovulation when estradiol is peaking, in vitro data from engineered ligaments have shown that short-term exposure to estradiol (48 h) negatively influences relative stiffness and maximal load before ligament rupture. A possible explanation for these observations is that estradiol inhibits the activity of the cross-linking enzyme lysyl oxidase. A lower load to failure has also been reported in ACL from rabbits, which have been treated with high doses of estradiol compared to controls. Furthermore, patellar tendon relative stiffness is lower in elderly women using estrogen replacement therapy (ERT) than in postmenopausal age-matched controls with low estradiol levels. Similarly, knee joint laxity is significantly higher in pregnant women in their third trimester compared to 5–7 weeks postpartum (38 out of 40 women) [25].

In summary, the present limited knowledge support a direct link between estradiol and tendon and ligament biomechanical properties, which may influence injury risk, when estradiol levels are high.

Relaxin is another hormone, which is positively correlated with the estradiol level and may have an impact on knee joint laxity particularly in pregnant women, but also female athletes. Relaxin receptors are present in the ACL. A small prospective study in elite female athletes observed a greater risk of sustaining an ACL rupture in athletes with highest relaxin levels. Nevertheless, the effect of relaxin is only sporadically investigated in perspective to variations in ACL injury risk during the MC. Furthermore, the relaxin level is observed to be higher in OC users, who seem to be in a lower risk of ACL injuries (see below); thus, relaxin is probably not a major explanatory factor.

38.5.2 Influence of OC on Knee Joint Laxity and ACL Injury Risk

A systematic review including seven studies has examined the association between the use of OC and ACL injury risk [24]. The number of participants in the studies ranged from 65 to 51,348. The authors concluded that the use of OC might reduce ACL injury risk by up to 20%. One of the included studies was a case-control study including 4497 operatively treated patients after ACL rupture and 8858 age-matched controls with no ACL injury [26]. The Danish Prescriptive Registry was used to obtain data on OC use. These data were combined with data from the Danish National Registry of Patients in regard to information about ACL injuries in operatively treated patients. In line with the overall conclusion of the review, an 18% reduction in surgery requiring ACL injury risk was reported among OC users (relative risk [RR], 0.82; 95% CI, 0.75–0.90) compared to never users of OC [26]. The potential protecting effect of OC on ACL injury risk may be explained by cross-sectional data, which has observed a lower tendon collagen synthesis rate in young OC users compared to age-matched controls. The latter may indicate a lower tendon collagen turnover, which may enhance possibility for introducing collagen cross-links and thereby improve tendon and ligament stiffness. Some, but not all, studies support the latter. The fact that OC users do not experience a peak in estradiol during the pill cycle as during an ovulatory MC may also positively influence ACL injury risk.

Noteworthy, this section has focused on the effect of female hormones primarily on knee joint laxity, the patellar tendon and the related ligaments. The female hormones may not necessarily affect other ligaments and tendons to a similar degree due to differential expression of receptors and different loading pattern. Furthermore, as previously described, there are many types of OC, and it may be a simplification to state that they influence the tendon and ligament structure and biomechanical properties similarly.

38.6 Biomechanical and Neuromuscular Gender Differences: Influence on ACL Rupture Risk

This section will focus on the following modifiable risk factors for ACL injuries: hamstring muscle strength and biomechanical and neuromuscular risk factors during sports-relevant movements where ACL injuries occur.

38.6.1 Importance of Hamstring Muscle Strength

The hamstring muscles play a key role in protecting the ACL and are the single most important synergist to the ACL. When the quadriceps muscle contracts during knee extension, it produces substantial anterior-directed shear of the tibia relative to the femur at extended joint angles. This shear can be counteracted not only by the ACL but also by hamstring muscles co-activation. Thus, low muscle strength of the hamstrings relative to quadriceps has been proposed to increase the risk of knee joint injuries [27]. The hamstrings-quadriceps (H:Q) strength ratio based on peak force values has traditionally been used to describe the potential for knee joint stabilization and to quantify the risk of injury. However, no consistency exists as to whether female athletes display lower H:Q strength ratio than male athletes. One study found no gender difference in the H:Q strength ratio in a population of elite soccer players [27]. However, it was shown that female athletes displayed a reduced muscle strength capacity to exert force rapidly (rate of force development, RFD) compared to their male counterparts [27]. A similar study has not been conducted among handball players; however, a recent large prospective trial revealed that the H:Q strength ratio based on peak torques was not predictive of future ACL injury in 867 female elite handball and soccer players [28].

38.6.2 Biomechanical Risk Factors

In team handball, the highest frequency of ACL injuries is observed during noncontact side-cutting movements. Using highly accurate and reproducible 3D motion analysis techniques, it was reported that female athletes had a greater knee abduction angle when preparing to execute a cutting maneuver compared with male athletes [29]. It is not known if knee joint angles are different between genders in the handball side-cutting maneuver, but existing studies on side-cutting show that women produce smaller knee flexion angles and greater valgus moments during jumping and side-cutting than males. If the knee is subjected to rotational moments and *in valgus* position during side-step cutting, as studies indicate, then hamstring activation may be crucial for preventing a damaging strain of the ACL, especially among female athletes.

38.6.3 Neuromuscular Risk Factors

Before explosive movements like jumping, landing, running, and cutting, the involved lower limb muscles are innervated before ground contact in order to build up necessary force before the impact. Thus, high hamstring activation during 50 ms prior to initial ground contact is essential to produce sufficient hamstring force in the first part of ground contact. As ACL injuries are reported to occur during the initial phase of ground contact, low hamstring activation may reduce the potential for protecting the ACL.

Studies on gender differences in muscular activation during jumping or cutting activities have shown a tendency to higher activation of quadriceps and lower activation of hamstrings in females compared to males. In one study, female team handball players were found to display significantly lower hamstring EMG activity in the preactivation period during side-cutting than their male counterparts [30] (Fig. 38.3). The lower neuromuscular pre-activity of the hamstrings among females supports the notion that female athletes display different neuromuscular

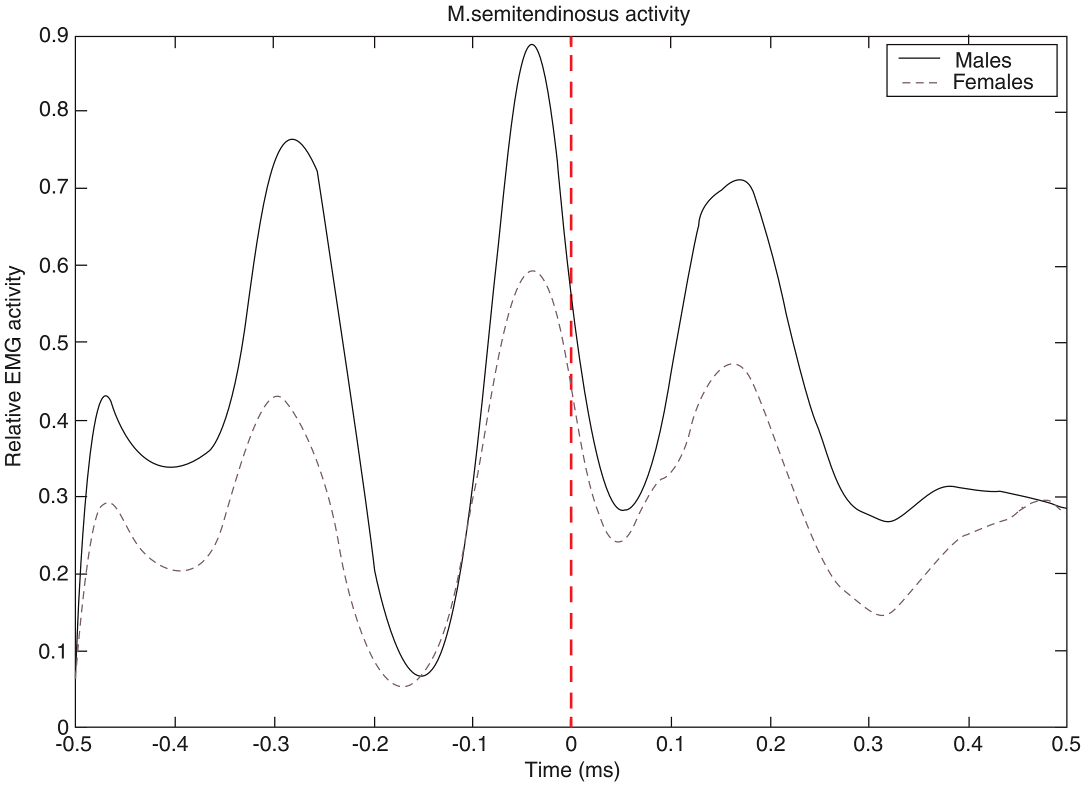

Fig. 38.3 Hamstring preactivation. The figure illustrates an example of the difference between female and male handball players in hamstring preactivation during a side-cutting maneuver. The vertical dotted line represents ground contact. The illustration is kindly provided by Jesper Bencke

strategy in situations where ACL injuries occur. Furthermore, the hamstrings have been shown to contract concentrically during the initial part of the ground contact during sidestep cutting, and thus the hamstrings may not be able to produce the same force with the given neural activation as if they were contracting isometrically or eccentric during the initial ground contact.

The abovementioned findings regarding biomechanical and neuromuscular properties underline the necessity to perform specific training that induce optimal strength and activation of the hamstrings. Thus, exercises that target the ability to rapidly exert force (RFD) as well as exercises that introduce proper alignment during high-risk movements like the side-cutting are essential components to implement in the weekly training routines see Fact Box 1.

Fact Box

ACL Injury Prevention Bullets

Injury prevention exercise programs can induce increased activity of hamstring muscles in female athletes during side-cutting.

The Nordic hamstring exercise can induce increased RFD of the hamstring muscles in female athletes.

38.7 Dietary Considerations Related to the Female Player

An appropriate energy and nutrient intake that matches periodized nutritional needs and athletic goals is the cornerstone of the athlete's diet (see

Chap. 7). Besides vitamin D and iron deficiency (see Chap. 7), one of the major nutritional concerns for female athletes is low energy availability (EA) with or without disordered eating (DE) behavior and eating disorders (ED). In this section, we will focus on definitions, etiology, consequences, prevalence, and management of this nutritional concern among female handball players.

38.7.1 Consequences of Low Energy Availability

Daily energy needs for elite female ball game athletes is ~ 3500 kcal, while energy intake among female handball players has been reported to be <3000 kcal. Female athletes in general are frequently reported to have similar or even lower daily energy intake compared to sedentary women, often due to an insufficient carbohydrate intake. Energy availability is defined as the ingested energy remaining for all other metabolic processes after the energy cost of training has been subtracted (Fact Box 2). Experimental studies in sedentary eumenorrheic women have shown that 5 days of EA less than 125 kJ (30 kcal)/kg FFM/day suppress the hypothalamic-pituitary axis hormones, like luteinizing hormone (LH) and triiodothyronine (T3), elevate cortisol, and reduce biomarkers of bone formation [31] (Fig. 38.4). Persistent low EA with or without DE/ED is associated with endocrine and metabolic perturbation leading to menstrual dysfunction and impaired bone health, referred to as the female athlete triad [32]. Recently, relative energy deficiency in sports (RED-S) has been introduced [33] in order to broaden the concept and to emphasize the complexity involved since other physiological aspects besides the reproductive function and bone health are affected, and that these problems not only affect female athletes but also males and recreational active people [33].

The suggested etiology of low EA in female athletes includes difficulties in increasing food intake to meet the high energy requirements during intensive periods either due to a low energy and carbohydrate dense diet or due to a primarily expenditure-driven suppression of appetite. Body

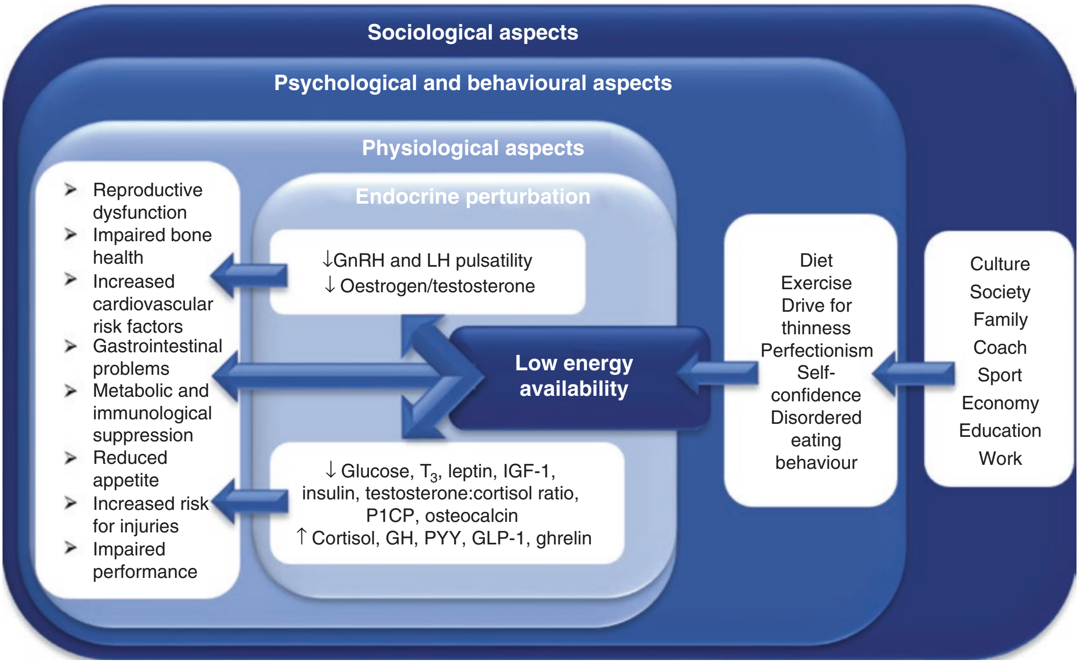

Fig. 38.4 Potential cause and effect diagram of low energy availability in athletes. The figure illustrates examples of potential sociological, psychological, and behavioral causes of low energy availability and some of the potential physiological effects in athletes

weight and body composition are important performance variables in many sports. Athletes also experience external pressure to conform to social norms concerning a fit body. A continuum model of DE is recognized, which starts with appropriate eating and exercise behavior, including healthy dieting and the occasional use of more extreme weight loss methods that progresses to chronic dieting, binging, and use of fasting, passive or active dehydration, laxatives, diuretics, vomiting, and excessive training. The continuum ends with clinically overt ED, such as anorexia nervosa, bulimia nervosa, binge eating disorder, or other specified and unspecified feeding or eating disorder (OSFED).

Independent on the etiology, the consequences of persistent low EA in female athletes typically comprises suppressed resting metabolic rate (RMR), gastrointestinal problems, and functional hypothalamic amenorrhea (absence of menarche >15 years or no menses during three consecutive months) or oligomenorrhea (menstrual cycles >45 days). The long-term and severe clinical consequences are impaired bone health (BMD Z-score ≤ -1) and increased cardiovascular risk factors (unfavorable lipid profile and impaired endothelial function). An increased risk for severe musculoskeletal injuries and impaired performance in female athletes has also been reported in female amenorrheic athletes [32, 34] (Fig. 38.4).

Fact Box

Definition of Energy Availability.
Energy availability is defined as the ingested energy remaining for all other metabolic processes after the energy cost of training has been subtracted.

38.7.2 Prevalence and Management of Dietary Applications for Team Handball

The prevalence of ED in ball game players has been reported to be lower compared to other sport categories such as endurance or aesthetic sports. Most of these studies, however, have used questionnaires and self-reported ED. Studies that have extended the methods to also include a clinical verification interview have found a higher prevalence in the athletic groups compared to aged-matched controls. In a Norwegian controlled study using clinical interview to diagnose ED among elite athletes, 24% of the football players, 29% of the handball players, and 44% of the endurance athletes met the DSM-V criteria for a clinical ED (such as anorexia nervosa, bulimia nervosa, or eating disorders not otherwise specified) [35]. Most of the handball players were diagnosed with bulimia nervosa or eating disorders not otherwise specified. However, 7% of the handball players met the criteria for anorexia nervosa. It is therefore noteworthy that handball players can be underweight, normal weight, or overweight, irrespective of low EA due to lowered RMR and of the presence of DE or ED [36].

Managing the athlete with a low EA may be challenging from a medical, psychological, and sport environment standpoint. Symptoms may be hard to discover, since body weight is often in the normal range, and some athletes will even deny claims about possible DE or ED behaviors. Therefore, professionals working with female handball players should have knowledge about possible risk factors and early signs and symptoms of low EA, along with the health- and performance-related consequences, how to approach the problem if it occurs as well as a strategy for a safe return to play (Fact Box 3). In terms of treatment, it must always take precedence over training and competition. The primary goals should be to optimize EA, to control and manage the athlete’s DE behavior (if present), to restore normal hormone levels, and to monitor and treat other medical complications resulting from low EA. The optimal treatment plan of an athlete with low EA includes a multidisciplinary intervention plan, and the medical team normally includes a physician, a gynecologist, a nutritionist, a physical therapist, an exercise scientist, and in the case of DE/ED, a psychiatrist or a psychologist. In addition, coaches and parents might be included in the treatment in order to coordinate the training and competition plans with the treatment strategy. The younger the athlete, the more the involvement of the family is recommended [32].

Fact Box

Early Detection of Risk EA Factors

Early detection of athletes at risk for low energy availability (EA) with or without disordered eating behavior or eating disorders is critical to prevent long-term health impairing conditions, and annual screening using self-reported questionnaires is recommended.

The periodic health examination and the preparticipation physical evaluation form include relevant questions possibly helpful for early detection.

The Low Energy Availability in Females Questionnaire (LEAF-Q) is a brief questionnaire on physiological symptoms linked to low EA that can also be used followed by in-depth and individual evaluation of players identified as being at risk.

The relative energy deficiency in sport (RED-S) clinical assessment tool (CAT) can assist clinicians in the evaluation of players at risk and the management of return to play decisions.

38.8 Pregnancy and Return to Sport After Pregnancy

During pregnancy, several questions may arise if a player wishes to continue participating in training and matches at the elite level as long as possible without jeopardizing their own health or the health of the fetus. The player may also wish to return as fast as possible postpartum, and there may be a pressure from the team and coach to do so. Despite this, research within this area is very sparse – and studies on elite athletes are almost nonexistent [37]. Regardless of any research finding presented here, it is important to emphasize that each female player in this scenario should be individualized. The player's participation should be discussed with the coaching staff and team doctors since each individual may feel differently during pregnancy and the symptoms as well as potential complications that may arise during birth or at the postpartum period may vary from athlete to athlete.

38.8.1 Playing During Pregnancy

For team handball players, the risk factors associated with playing can be divided into two major groups: the physiological risks/insults (intensity, duration, and frequency of the exercise) and risk of trauma (collision, falls, jumps, being hit, etc.). The latter may be hazardous for both the pregnant player and the child [38]. Joint laxity is markedly enhanced during pregnancy [25], which is associated with a higher risk of ligament injuries. In case of a maternal trauma, abruption of the placenta can occur, which may lead to fetal hypoxia or even fetal death [39]. Even though participation in elite matches during pregnancy may be associated with concerns, it should be emphasized that exercising during pregnancy is advisable and recommend [38], although the level and the type of training needs to be adjusted at an individual level [37, 38].

Increased body weight changes the center of mass as the pregnancy progresses augmented by the growing belly and breasts and the increased spinal curvature of the lower back, which may ultimately change both biomechanics and increase the risk of falls [38]. Combined with the increased laxity of ligaments, it is therefore important that female handball players take care to avoid unnecessary load on joint and ligaments particularly during training, which is a more controlled environment compared to matches. Another area of focus for the pregnant female athlete should be on pelvic girdle pain and urinary incontinence, which may increase during pregnancy due to hormonal changes and increased load on the pelvic floor, particularly during jumps and other high-impact exercises [38]. Non-weight-bearing exercise such as cycling and workout at a cross-trainer as compensatory fitness training may be beneficial to incorporate gradually as the pregnancy progresses to minimize reduction in fitness level and control weight gain (Table 38.1).

Reasons to continue exercising at a moderate level throughout the pregnancy include indications that a gestational weight gain (GWG) above the recommendations can influence pregnancy outcomes and return to play [38]. It may also take longer to return to an optimal competition weight with an excess GWG [38]. A study reporting

Table 38.1 Recommendations for total gestational weight gain in singleton pregnancies defined by pre-pregnancy body mass index (BMI) [44]

Pre-pregnancy BMI (kg/m^2)		Total weight gain (kg)	Weekly weight gain in the second and third trimester (kg)
<18.5	Underweight	12.5–18.0	0.44–0.58
18.5–24.9	Normal weight	11.5–16.0	0.35–0.50
25.0–29.9	Overweight	7.0–11.5	0.23–0.33
>30.0[a]	Obese	5.0–9.0	0.17–0.27

[a] BMI: class I (30–34.9), II (35–39.9), and III (>40)

GWG in elite athletes found that in 40 Norwegian elite athletes and age-matched controls with normal pre-pregnancy BMI, the self-reported mean GWG was lower in the athletes compared to controls (13.9 SD 6.9 kg vs. 17.5 SD 9.1 kg, $p = 0.06$) [40]. This suggests that athletes may already have a more controlled GWG or possibly that maintained physical activity during the pregnancy helps reducing GWG. Exercise recommendations for pregnant women: see Fact Box 4.

38.8.2 Return to Play Postpartum

The postpartum period is usually defined as the first 6 weeks after pregnancy [41]. Strength training of the pelvic floor muscles is recommended, but otherwise in many countries women are not encouraged to exercise during this period and should accept that the body needs to recover [41]. Nevertheless, time to recovery may vary from player to player and may depend on individual factors such as previous fitness level, and whether the delivery was complicated and/or surgery was needed. Early return to strenuous exercise may increase the risk of urinary incontinence and pelvic organ prolapse, but there is a lack of research to support this statement in relation to female athletes [41]. In 40 elite Norwegian athletes, the prevalence of stress urinary incontinence was 29% at 6 weeks postpartum [40]. At least in theory, female athletes who experience such problems are recommended to minimize activities that generate large increases in intra-abdominal pressure and/or high-impact loading [41]. There is strong evidence for pelvic floor muscle training as treatment of urinary incontinence postpartum [41].

Diastasis recti abdominis is a condition where the two large parallel band of muscle in the abdomen (the recti abdominis), which normally meet in the abdominal midline, separate. This is caused due to uterine stretch during pregnancy and may result a large bulge in the middle of the abdomen as well as weakness. It usually resolves spontaneously during the postpartum period (usually within 8 weeks); however it may persist in some cases. In the general population, postpartum prevalence of diastasis recti abdominis varies between 30 and 68% [41]; however, there are no reports on the prevalence in elite athletes, and there is insufficient evidence in regard to recommendation for an optimal exercise program postpartum or decision making for surgery to restore diastasis [41]. Furthermore, following a caesarean section, it should be recognized that the abdominal fascia needs a longer period to recover and regain its original tensile strength. In one study, the abdominal fascia had regained 51–59% of its original strength 6 weeks post surgery and 73–93% after 6–7 months [42].

There is a lack of studies with regard to timing for return to play postpartum in female elite athletes. However, maintaining a high fitness level during pregnancy seems to be possible, which may reduce the time for return to sport. Exercise training does not seem to impair breastfeeding, and breastfeeding may benefit the athlete in regard to postpartum weight loss. A moderate weight loss in the breastfeeding period does not have negative impact on neonatal weight gain [43], yet it is important to increase fluid intake if exercise intensity and duration are increased during times of breastfeeding.

In summary, female handball players should resume exercising gradually [41]. First step is to improve the general fitness level by following a modified training program. The second step will be to take part in handball training, and optimally the final step will be to return to the same or higher performance level as before pregnancy. Coaches and medical staff in the handball perimeter should be aware of the various aspects involving the pregnant player during and after pregnancy and be attentive to the needs, symptoms, and individual progression/recovery pace of each player. The progress of the training program should be discussed with health professionals. The timing of the return will vary due to individual differences and factors during pregnancy, delivery, and early postpartum time.

Fact Box

Exercise Recommendations During Pregnancy [37, 38]

Pregnant women are recommended to perform exercise – under supervision and monitored by health professional.

Exercise during pregnancy can help to prevent inappropriate weight gain, gestational diabetes, and pregnancy-induced hypertension, and possibly reduce length of labor, but will also help to maintain fitness level.

Female handball players have to take into account that joint laxity is progressively enhanced during pregnancy, and the risk of ligament injuries is greater during peak load in extreme positions during training and matches. Fall may also be traumatic for both mother and fetus.

The need for adjustment of the training volume, intensity, frequency, and type of training will depend on the individual player, but a gradual change to compensatory non-weight-bearing exercise training with moderate intensity is advisable for most athletes to minimize risk of complications. Furthermore, resistance-training programs should be modified to include more repetitions at a lower weight and longer breaks.

It should be emphasized that every woman and every pregnancy is different. The pregnant athlete should not ignore warning signs, but consult health professionals if they arise.

38.9 Take-Home Messages

The understanding of how endocrine factors influence athletic performance in females has increased within the last decades. Nevertheless, knowledge about the effect of endogenous and exogenous female hormones on athletic performance and related determining physiological factors are still inadequate. In many cases the results are conflicting, which may be related to poor study design, e.g., small sample sizes, no determination of hormone levels during MC and OC cycles, variations in test protocols, no dietary control, variation in training status, and the use of different types of OC preparations.

Despite these discrepancies, current data suggests:

- Adaptations to strength training may be improved when intensified training is performed during the FP rather than during the LP.
- Fat utilization seems to be higher during submaximal exercise performed during mid-LP, which may improve endurance performance capacity.
- Exposure to high estrogen levels is associated with reduced tendon and ligament stiffness.
- In female handball players, ACL injury risk is increased around ovulation in non-OC users.
- Specific training that (1) optimize strength and activation of the hamstrings, (2) improve rate of force development during handball-specific movements, and (3) focus on proper alignment during high-risk movements like the side-cutting is suggested as important prevention strategy to reduce the risk of ACL injuries.
- Female handball players are at risk for RED-S, and the sports medicine teams should perform regular screening in order to ensure early identification of symptoms such as menstrual dysfunction and recurrent overuse injuries (Fact Box 3) and initiate evidence-based treatment and an individual plan for return to play.

Although the abovementioned changes seem small and often nonsignificant, the same changes may be meaningful in an athletic context and eventually influence the performance in training and during match play. Therefore, athletes and coaches may benefit from an awareness of individual changes in sport-specific performance parameters (e.g., measurement of variations in jump height during the menstrual cycle) during the MC or OC cycles. This will demand an inclusion of sport-specific tests of individual response to hormonal fluctuations during the menstrual cycle in the regular test battery. Furthermore, we will recommend that the sports medicine team (if available) perform regular screening for menstrual dysfunction and regular heavy bleeding in order to prevent long-term health and performance-impairing consequences.

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39

The Young Handball Player

Leonard Achenbach

39.1 Introduction

Participation in team handball is popular in Europe for children and adolescents. In the largest handball association in the world, Germany, more than 40% of all players (305.230) participate in organized youth team handball each year [1].

Team handball is by its very nature competitive and already during youth it is performed at different levels, with elite young athletes at the top performance. The elite young athlete is one who has superior athletic talent, undergoes specialized training, receives expert coaching, and is exposed early to many competitions. At the elite level, national and international handball federations have organized youth competitions in various age classes. International competitions begin from u-17 for women and u-18 for men. These competitions also represent important showgrounds where young talented athletes are identified for a future professional career.

Players in this age group undergo growth and development at an individual rate, yet physical growth and cognitive development influence successful participation in youth handball. Engaging in team handball at a young age has important physical health benefits but also involves risk of injury. Youth handball players may be particularly vulnerable to injury due to growth-related factors such as the growth spurt, susceptibility of the growth plate, and differing physiological response after training and match load [2]. This would seem particularly true at elite level given the intensive training programs and high frequency of participation in competitions. Although it is impossible to eliminate all injuries, attempts to reduce risk of injury are warranted.

The purpose of this chapter is to provide a current overview of risks related to physical and psychological injury that may be encountered by youth handball players, especially in the elite youth setting. Relevant research from other team sports is included to augment the limited research related to youth team handball, especially with regard to psychological injury. Most research arises from elite-level youth handball and will therefore be discussed in more detail.

39.2 Relative Age Effect

Having a birth date immediately after the classification cutoff for age-based youth sport provides a developmental advantage over those born immediately before this date up to 1 year. This “relative age effect” (RAE) advantage in development is seen to be enough to improve selection likelihood for youth athletes. For example, a player born on January 1 with a cutoff for his age

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class on December 31 has an advantage of half a year over a player born on June 30 and even one total year over a player who was born on December 31 in the same year.

Strength- and running-intensive sports where height and strength are favored are affected most from RAE. Schorer has shown significant differences in German team handball with almost 40% of regionally selected male athletes born in the first quartile, while <15% were from the last quartile (Fig. 39.1) [3]. This effect has been less significant for female players, probably due to a lower depth of competition and thus a lower number of participants from which selection can occur [3]. This effect is also less prominent in the A-squad, probably because at the adult level in elite sports, early age-related advantages in development would have disappeared (Fig. 39.1). However, once selected into high-level professional academies at a young age, players are much more likely to reach the ranks of senior professional play, whereas those excluded are not [4]. Helsen suggested that those selected have greater access to resources like high-quality coaching, practices, and equipment for event-specific skills [5].

Anthropometric differences of players have been identified as playing an important role in performance and selection. Independent of the birth date, selected players had a similar level of athletic performance. This indicates younger players only have a chance of being selected if they possess a higher level of athletic performance, while older athletes have an additional higher chance of being selected if they are physically bigger. Anthropometric differences therefore have an important role when it comes to talent selection in youth sports [6, 7]. One influencing factor is the match characteristics of team handball which allows body contact and promotes stop fouls to interrupt the play flow. Another influencing factor may be the modern concept of high pressing in defense of the national handball federations. For example, in the German Handball Federation (DHB), u-16 players must defend in the high-pressing 3:2:1 system. In this defensive concept, older players may have an advantage during match play due to their likely athletic superiority. In both cases, smaller and lighter players may experience disadvantages.

Most training exercises are built the same for all players in one team. This way, RAE exerts the

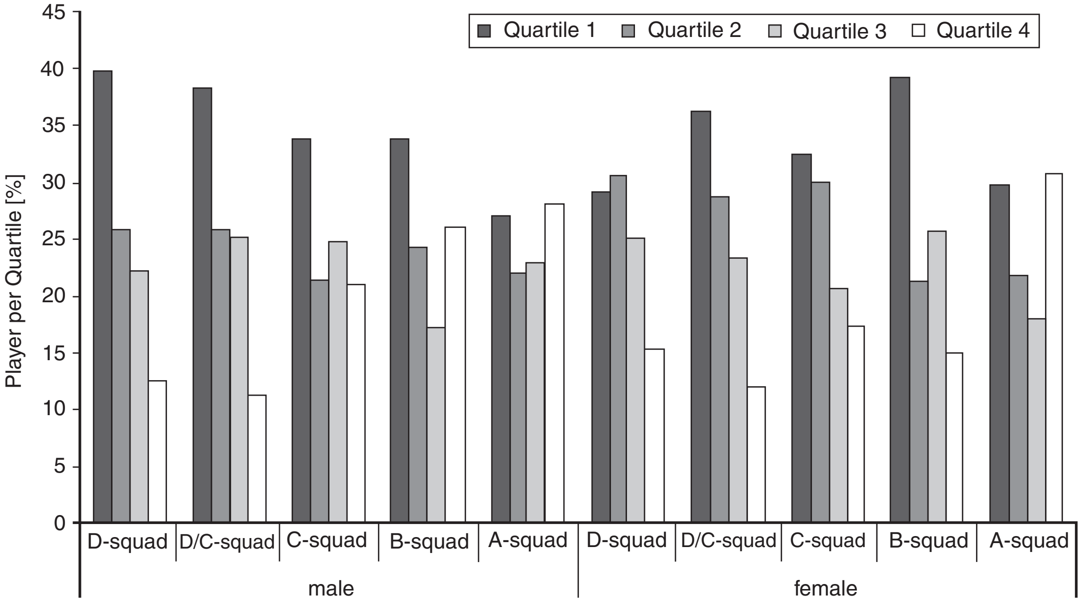

Fig. 39.1 Distribution of birth quartiles for male and female national handball players per squad in percent, from Schorer [3]

risks of injury of the relative younger and therefore athletic weaker players because these players may not be able to withstand (yet) the training demands compared to their relative older peers. Playing several times a week against peers that have athletic superiority, late-developed players are exposed to higher training and match loads than early-developed players in the same team. If there is no adequate individual periodization for each player within a team, players have to invest more to compete with their peers. Subsequently, the training load is higher and the risk of injury may increase.

In a study from a regional hospital database, prepubescent patients showed significant RAE on sports injury [8]. Those born in or right after the cutoff month for their sports were underrepresented in the study cohort relative to their representation in the general population. However, analysis of the pubescent age group indicated that by the time these individuals reach high school, a reverse RAE may exist. Specifically, the athletes in this age category with a sports injury were overrepresented, as compared with the general population, followed by a steady decline in each month thereafter. This finding may be explained, in part, by the notion that the relatively older, and more developmentally advantaged athletes for sports participation, receive more attention from coaches, parents, and training staff, ultimately leading to increased athletic exposure over time.

Another study which followed a cohort of 1190 athletes, with age ranges of 7–18 years, reported that injured athletes are older and spend more total hours participating in physical activity [9]. Additionally, this study showed that sports specialization is an independent risk factor for athletically related injuries. Therefore, the authors conclude that relatively older and early-developed children in sports settings may have persevered in their sports and may then consequently possess a greater risk of sustaining a sports-related injury.

The impact of relative age on youth sports demonstrates that activity cutoffs, which are often arbitrary dates selected to ease organization, may influence risk of sports-related injuries. Further research may help answer the question if the organization of youth team handball may benefit from consideration of a child’s size and development, in addition to age.

39.3 Sports Specialization

The support for the underlying assumptions of early specialization is quite compelling. One of the most robust relationships ever identified in behavioral science is the positive relationship between time spent practicing and level of achievement [10]. In the year 1973, the “10-year rule” was introduced, a general criterion of expertise grounded in evidence that 10 years was a sufficient period of time to amass the level of knowledge necessary to become an expert [11]. This “rule” has been first observed in chess and since been observed in several other domains and sports [12]. Two decades later, the theory of deliberate practice developed by Ericsson advanced the general concept of expertise development through focused training over time with one major stimulation [13]. They suggested that it was not simply any form of training that differentiated individual performance, but the engagement in a specific form of training they termed “deliberate practice.” By definition, this type of training involved practice activities that were effortful, low in inherent enjoyment, and purposefully designed to address current areas of weakness [13]. Ericsson also argued that it was not simply the accumulation of deliberate practice hours that will lead to superior levels of performance, but this accumulation must coincide with certain crucial periods of biological and cognitive development. Finally, they argued that early sports specialization was important for future success because the earlier one starts adhering to a strict training regime, the quicker one will attain their desired level of skill. This model of athlete development has since been superimposed on young handball players, and early sports specialization has since been promoted as the key to success for many coaches and parents.

Sport specialization may be considered as an intensive, year-round training in a single sport at the exclusion of other sports and early involvement in competitions [12, 14]. Coaches (and parents) believe that focusing on a single sport is advantageous to compete on higher level. The emphasis on competitive success has therefore become widespread in many youth sports [15]. This has resulted in an increased pressure to begin high-intensity training at even younger ages, and training methods designed for male adults have been superimposed on youth athletes of both gender. Yet, there is concern that early sport specialization and elite-level organized youth sport may have potential negative effects and increase the rates of acute injury, overuse injury, and sport burnout, but this relationship has yet to be demonstrated. Sport burnout is a consequence of chronic stress that results in a young athlete stopping participation in a previously enjoyable sport.

Concerns have also focused on associations between early intensive training and negative developmental consequences. Coaches and parents may lack knowledge about normal development and signs of readiness for certain tasks, physically and psychosocially. Readiness for sports is related to the match between a child's level of growth and development and the demands of the sport. Chronological age is not a good indicator because motor, cognitive, and social skills progress at different rates, independent of age. This can result in unrealistic expectations that cause children and adolescents to feel as if they are not making progress in their sport. Consequently, children may lose self-esteem and withdraw from the sport.

Athletic identity has been related to both positive and negative performance outcomes [16]. Defined as the degree to which an individual identifies with their athletic role, elite athletes with strong and exclusively athletic identities risk the possibility of their self-worth and esteem becoming dependent on athletic performance [17]. Subsequently, if performance falls below perceived expectations, an athlete's feeling of self-worth may be threatened [18].

39.4 Handball-Specific Adaptions

Different sports are characterized by a multitude of highly specific, stereotypical patterns of movement. When the movements are performed at sufficient magnitudes for a long period of time, these sports-specific motor stimuli evoke specific responses in which certain biological structures undergo adaptations that enable the athlete to adequately "process" the loads. These sports-specific adaptions affect bones, ligaments, and musculoskeletal and myofascial structures and are characterized in all sports by an asymmetrical distribution of loads between the right and left sides of the athlete's body, i.e., team handball with normally one dominant throwing shoulder.

Generally the adaptations heighten the quality of the sport-specific movement patterns and thus have a positive effect on the athlete's performance in that particular sport. Pieper investigated 51 male adult professional handball players and determined humeral retrotorsion by radiograph [19]. The retrotorsional angle of the humerus was an average of 9.4° larger in the dominant side than in the nondominant, with a side-to-side difference up to 29°. But players with chronic shoulder pain did not exhibit this increase, even showing an average decrease of humeral retrotorsion of 5.2° in the throwing arm. The humeral retrotorsion increase can be explained as an adaption to extensive external rotation in throwing practice during growth. Athletes who do not adapt this way seem to have more strain on their anterior capsules at less external rotation and develop chronic shoulder pain because of anterior instability.

On the other hand, many of these adaptations cause changes in muscular loads and can sometimes lead to the overuse or unphysiologic loading of certain musculoskeletal structures and in so far could create an additional risk factor, exceeding the stress tolerance of the structures, and resulting in injury [20]. Looking at 139 junior handball players of both sexes, we could demonstrate an average internal rotation loss of 3.7 SD 10.8° and an external rotation gain of 8.1 SD 13.7° in the dominant shoulder compared to the nondominant shoulder (personal communication).

This shows players adapt early to the demands of the match, yet this has been associated with mixed results for shoulder overuse injury risk in adults [21, 22]. Further research should elaborate the consequences of these sports-specific adaptions, especially in junior and adolescent players.

39.5 Training Load and Injury Risk

Training load is one of multiple risk factors for sustaining an injury in team handball. Training workloads are applied to athletes with the goal of inducing positive physiological changes and maximizing performance. The various biological adaptations induced by (appropriate) training increase athletes' capacity to accept and withstand load and may thus provide protection from injuries. The aim of load management is thus to optimally configure training, competition, and other load to maximize adaptation and performance with a minimal risk of injury.

An external training load refers to any external stimulus applied to the athlete, whereas the individual biological response to this external load is called internal load [[23], 66]. In team handball, the former refers to the quality, quantity, organization, and content of physical exercises prescribed by the coach, and the latter is of physiological and psychological nature. The external load stimulates a biological response and eventually adaption of the human body's systems. The stimulus for training-induced adaptions is the actual physiological stress, i.e., the internal load, imposed on the football players by the external load [24, 25]. Training results in temporary decrements in physical performance and induces fatigue. These decrements are typically derived from increased muscle damage, impairment of the immune system, imbalances in anabolic-catabolic homeostasis, alteration in mood, and reduction in neuromuscular function [26–31, 65]. Gender differences have not much taken into consideration yet since, for example, estrogens have been shown to protect against reactive oxygen species [32].

The resultant fatigue after a training load can take up to 4–5 days to return to baseline values after the respective training. This fatigue follows a supercompensation phase, whereby the body adapts to increase the specific capabilities affected by the initial stressor [33]. In sports that have frequent training and competition, such as football and team handball, fatigue may accumulate over time [34].

Periodization was developed with the aim of manipulating these adaptive processes and effects. Handball athletes and coaches push their training to the limits by means of volume and intensity to maximize their performance. The aim of load management is to optimally configure training, competition, and other load to maximize adaptation and performance with a minimal risk of injury. Load management therefore comprises the appropriate prescription, monitoring, and adjustment of external and internal loads. But limited information exists on the training dose-response relationship in amateur and elite handball athletes. In many European top leagues, top teams compete two games per week during several periods within a season, and players may participate in 50–80 games during a season. During these congested periods, players have only 3–4 days of recovery between successive international and national games, which may be insufficient to restore normal homeostasis [27, 35]. Without sufficient regeneration after a match, players will begin their next match with a certain amount of fatigue with the potential of causing performance impairment and injuries in the short and long term [36, 37].

The majority of studies on the relationship between training load and injury risk in team sport have used assessment of absolute load, irrespective of the present or past rate of load application. Absolute training load is the total of all training sessions performed within a specified period, such as a single day or 1 week. Both low and very high acute training loads have been associated with increased risk of injury in team sports [38–41].

Gabbet proposed the idea of a player's threshold, i.e., the amount of training load that could be sustained before an injury occurred [41]. He suggested this threshold decreased during the season, potentially as players became fatigued when compared to preseason thresholds. In this sense, low acute training loads may be beneficial for players, as some studies indicate. At present knowledge, moderate-to-high workloads can protect best against injury [42].

Series completed in cricket, rugby league, and Australian football have shown that if an athlete's training and playing load for a given week (acute load) spike above the chronic load over the past 4 weeks in average, they are more likely to be injured [43]. Møller investigated the weekly training and competition hours of 679 elite youth players in the age of 14–18 years. She found that a large increase in weekly handball load increases the shoulder injury rate, particularly in the presence of reduced external rotational strength or scapular dyskinesis [44]. These findings demonstrate a strong predictive relationship between acute/chronic load ratio and injury likelihood.

Fact Box
In team handball youth setting, coaches must be aware of the training loads of their players and plan with caution if the acute/chronic ratio may peak. This is true especially in or right after school holidays with many players not physically active and on holidays with their families. In the elite setting, quantifying the loads the athlete's staff is expecting may help to prevent injuries.

39.6 Phases with Increased Risk of Injury

In addition to the general handball load applied, specific phases of a handball season or handball career are assumed to have an increased risk of injury, especially ACL tear.

The preseason period and the first match days of a new season have an increased risk of ACL injury in amateur and professional handball. The series of summer break with loss of fitness, muscle force, and coordination, and sudden physical overexertion at the beginning of the new season are assumed to let this time window appear more prone to ACL injuries. In phases of neuromuscular fatigue during preseason, the players have a decreased proprioception which results in increased load of the joints of the lower extremities. Counter movements from full sprint, rotational, or valgus movements may then result in overload of the knee joint and subsequent ACL tear. For young handball players, this risk may arise especially in amateur setting, which are more dependent on school holidays and training facilities may not be accessible to enable normal training periodization.

The increase of physical load in a handball player may also arise if a player changes its handball team, especially if this new team plays in a more professional and demanding level, for example, in a higher-performing league. A promotion of a team into a higher league also increases the demands of the player. Luig et al. (submitted) could show an increase of injury incidence in the second national division to almost the same level of the first national division within the first two seasons after restructuring the second league two-division system into one single national second league.

The transition from junior to senior sports also appears to present a dangerous phase. Söderman et al. found an increased risk for ACL tears in female junior football players participating in senior football [45]. The same could be established for male adolescents by our own data (not published). This topic is especially important for permits for junior players that want to play in professional senior handball. No scientific data has been established, but young players should be treated with caution to enable neuromuscular adaption and sufficient regeneration.

In case of transition to a secondary sport school, one study followed six young female handball players aged 13–14 years. The study recorded that the players experienced many stressors due to significant increase in training volume and reduction in sleeping time and three girls developed severe, long-lasting injuries [23].

Fact Box

In team handball youth setting, coaches must be aware of vulnerable phases with increased risk of injury. These phases comprise the preseason period with sudden increase of physical load, the transitions into a higher league or better playing team, from junior to senior sports, and to a secondary sport school.

39.7 Injury Pattern in Youth Handball

Little is known about the injury pattern of young handball players. The most common injury in elite youth handball involve the lower extremity, accounting for more than half of the overall injury rate in youth sport [46–48]. The ankle is the most frequently injured body site, followed by the knee. The most frequent severe injuries have been shown to be knee injuries, especially ACL tears, in the age group of 15–19 years. Female sex is associated with a higher ACL injury rate, and the ACL injury rate increases for girls in their adolescence [49, 50].

There are contradicting reports in the literature when comparing injury rates in youth and adult players, with recent reports showing higher prevalence in young players (Table 39.1). This could be the result of an overall low number of epidemiological studies in youth handball, different injury definitions, different sampling methods, and only several recent reports on overuse injuries.

Overuse injuries are underestimated in the literature because most of the epidemiological studies define injury as requiring a time-loss from participation. Few studies have investigated the overuse symptoms in youth handball players. Møller described 14% as shoulder overuse injuries and an incidence rate of 1.4 per 1000 playing hours in 679 players [44]. Looking at elite youth handball, 23.4% of players experienced symptoms of overuse injury in the back, 18.5% in the knee, and 16.9% in the shoulder (personal communication). Overuse injuries occur due to repetitive submaximal loading of the musculoskeletal system when rest is not adequate to allow for structural adaptation to take place. Injury can involve the muscle-tendon unit, bone, bursa, neurovascular structures, and physis. Overuse injuries unique to young athletes include apophyseal injuries and physeal stress injuries, and imbalances between the skeletal growth and soft tissue adaptions, i.e., muscles, may make this population more susceptible to injuries and prone to injuries unique to adolescents.

In other sports, a femoroacetabular impingement has been associated with the frequency of practice during adolescence. A cam deformity is probably a structural bony adaption resulting from high impact hip loading, while the proximal femoral growth plate is open. The results of one study, for example, suggest a dose-response relationship between the frequency of football practice during skeletal maturation and the presence of a cam deformity in adulthood, as a cam deformity was less likely to develop when adolescents started to play frequently (>4 times/week) from the age of 12 as compared with those who started playing frequently before the age of 12 years [51].

Sport injury not only reduces future participation in physical activity but may also lead to posttraumatic osteoarthritis (PTOA). Youth handball players and younger adults may develop PTOA prematurely as a result of joint injury sustained in their youth. Whittaker et al. reported evidence that young adults reported greater clinical symptoms consistent with the onset and development of PTOA and are at greater risk of being categorized as overweight compared to matches uninjured controls [52].

Previous joint injury, history of meniscectomy, and ACL rupture have been identified as significant risk factors to develop PTOA in the knee [53, 54]. In case of an ACL injury in youth players, the safest and most effective technique for ACL reconstruction in skeletally immature patients is currently unknown. For example, transphyseal ACL reconstruction with metaphyseal fixation has to consider laxity, potential growth changes, and sports ability. For further information, Chap. 20 will highlight more data about the decision-making.

Table 39.1 Reported injury rates in youth handball players

Author (year)	Age group and gender	Number of participants *n*	Injury definition	Injury rate per 1000 h (match/training)	Important findings	Data collection
Nielsen and Yde (1988) Beijer et al. (1991)	7–18 years	221	Time-loss	8.9–14 (match) 1.7–4.3 (training)		Prospective
Dirx, Bouter et al. (1992)	12 and older	642	Medical attention and time-loss		Higher risk for players >20 than <20 years of age	Case-control study
De loes et al. (1995)	14–20 years	Not reported	Time-loss	0.7 (playing)	Lower injury risk in adolescents	Insurance records
Wedderkopp, Kaltoft et al. (1997)	16–18 years, female	217	Medical attention and time-loss	41 (match)		Retrospective
Wedderkopp, Kaltoft et al. (1999)	16–18 years, female	237	Medical attention and time-loss	23 (match)		Prospective
Wedderkopp, Kaltoft et al. (2003)	14–16 years, female	163	Medical attention and time-loss	52 (match)		Retrospective
Olsen, Myklebust et al. (2005)	15–17 years	1837	Medical attention and time-loss	0.6 (training) and 10.3 (match) (control group)		Prospective, randomized controlled study
Olsen, Myklebust et al. (2006)	15–18 years	428	Medical attention and time-loss	0.6 (training) and 8.3 (match) in males 1.0 (training) and 10.4 (match) in females		Prospective
Moller, Atterman et al. (2012)	Senior, u-18 and u-16	517	Time-loss	23.5 for seniors 15.1 for u-18 11.1 for u-16 (all match)	U-18 male players have an overall 1.8 times higher injury risk compared to female	Prospective
Aman et al. (2016)	0–100 years	16,456	Time-loss		Injury proportions differ for age groups: 10–14 years (21%), 15–19 years (41%), 20–24 years (20%)	Insurance records
Achenbach et al. (2017)	14–18 years	279	Medical attention and time-loss	1.85 (playing)		Prospective, randomized controlled study

39.8 Injury Prevention in Youth Team Handball

There is adequate evidence arising from injury prevention studies of youth handball teams to prevent injuries in amateur and elite handball settings. The focus of this research has been primarily on neuromuscular training programs. On the basis of the most common injuries involving the lower extremities, the focus of much of the evidence surrounding injury prevention in youth handball has been on reducing the risk of lower extremity injury, especially severe knee injury and ACL tear [46, 55, 56].

Poor postural control and muscular weaknesses have been assumed to be a reason for increased susceptibility to injury of the lower extremities [57]. Injury prevention programs have therefore focused on proprioceptive training modules with or without the use of additional equipment, such as balance boards and muscular strengthening exercises. These programs improved sufficiently proprioception, postural control, and muscular strength with good results in reducing injury rates, particularly of the lower extremities [46, 55, 56, 58].

Different techniques of side-cutting manoeuver have been shown to predispose to an increased knee abduction loading and subsequently to an increased risk for ACL injury. The main technique key points are a cutting width, external rotation of foot, and body’s center of gravity above the side-cutting knee. All of these aspects of safe side-cutting maneuvers are best taught in the young handball age.

An additional aspect for improving injury prevention and reducing injury in team handball is the compliance of the players with the program. Players who fully comply with the training modules sustain significantly fewer injuries than less compliant players [59]. To increase compliance with the training program, coaches should therefore be able to modify the prescribed exercises to an age-adjusted level. Interviews with team coaches have shown that other aspects positively influencing players’ compliance are a positive attitude toward injury prevention, which correlates with high compliance and a lower risk of injury. Team coaches of young handball players should therefore inform about injury risks and emphasize the importance of injury prevention exercises on a regular basis.

In general, injury prevention programs have been shown to be very effective in female athletes, and in this group more effective in the adolescent age than in older age groups, and should therefore already be implemented at a young age [60]. Multiple sports have been shown effective in preventing injuries and burnout and should therefore be promoted by coaches, clubs, associations, and parents [61, 62]. The diversified sports training during early and middle adolescence may be more effective in developing elite-level skills in the primary sport due to skill transfer [15].

In summary, the most important role of injury prevention in youth team setting has the handball coach, as he configures the training. The role of the coach in regard to injury prevention in youth handball comprises implementation of good warm-up habits and injury prevention exercises, teaching techniques correctly, and optimally manage training in regard to load and regeneration. In case of an injury, first aid should be applied properly [63]. All these injury prevention measures should therefore be mandatory as part of the education program for team handball coaches [46, 64].

39.9 Take-Home Message

Engaging in team handball at a young age has important physical health benefits but also involves risk of injury. Little is known about injuries of young handball players, but the few existing studies point to a slightly different injury pattern than their senior peers. Sports-specific adaptions occur early and may predispose to acute and overuse injuries. Late developers are probably more susceptible prepubescent, while early developers have a higher injury risk in and after pubescence. Youth handball players may have particularly vulnerable phases with increased risk of injury. These phases comprise the preseason period with sudden increase of physical load, the transitions into a higher league or better playing team, from junior to senior sports, and to a secondary sport school.

Young handball players therefore need special consideration from all team officials. Implementation of good warm-up habits and injury prevention exercises, teaching techniques correctly, and optimally manage training in regard to load and regeneration are key factors for injury prevention in the youth team handball setting.

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Training Load Issues in Young Handball Players

40

Martin Asker and Merete Møller

As in many youth sports, handball provides kids and adolescents with the opportunity to develop physical fitness including coordination, speed, endurance, agility, power and strength as well as develop social skills. Indisputable, participating in sports activities from a young age has numerous health and social benefits. However, this development of physical fitness requires that the player can adapt to the applied training load. Otherwise, there is an increased risk of injuries or non-functional overreaching. Further, there is also a chance that the player will lack the motivation to continue with handball, due to either too much pressure or persistent or recurrent injuries. In this chapter, we will outline potential risk scenarios of overload specifically in the young handball player aged 12–19 and how to address these risk scenarios.

40.1 Overuse Injuries in Young Handball Players

Handball is one of the most injury prone team sports, and the young handball player is not excluded. The total injury incidence, of both traumatic and non-traumatic injuries in youth and adolescent handball players, has been shown to be between 8.9 and 41.0 injuries per 1000 match hours and between 0.6 and 2.6 injuries per 1000 training hours [1–3]. The proportion of overuse injuries on youth handball has been reported to be 21–37% [2, 3]. However, overuse injuries are most likely to be underestimated since most of the studies have defined an injury based on time loss from the game and handball players tend to continue play even though they have an overuse injury [4]. For instance, a recent study has demonstrated that in adolescent elite handball players, aged 15–19, the season prevalence of substantial shoulder problems leading to moderate or higher reduction in performance or practice is 23% [5].

Injuries in the young player are worrying for several reasons. First, the young player may sustain some specific severe injuries that could not only end the handball carrier at an early age but also affect physical activity later on in life, e.g. physeal injuries, stress fracture and ACL injuries. Secondly, and more commonly, injuries during

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this period could affect the development of physical fitness and performance, especially during the adolescence. During the youth and adolescent period, one of the goals is to prepare the player for the training load that he or she will be exposed to during their career. During the season, the goal is to build up tolerance to the training load that he or she will be exposed to during the coming season and so on. An injury during this period could produce a "gap" where the player does not progress in physical fitness, while the game demands increase (e.g. higher intensity, more training hours, longer matches, larger and heavier ball, bigger opponents). This is typically the case with sustained overuse injuries where the player could go on for several month or even seasons with an "on-off approach" and become a "chronic rehabber" instead of developing the physical fitness that is required [6]. Further, recurrent and persistent injuries could drain the motivation, leading them to quit playing handball.

40.2 Critical Periods During the Young Player's Handball Career

There are several critical periods during the young handball player's career with a risk of overload and potential overuse injuries as a consequence.

40.2.1 Biological and Chronically Age Growth Spurts

Players from the same chronological age may vary extensively in biological maturity, especially during the adolescence [7]. This means that players in the same adolescent team have different preconditions and it is important to consider this when planning training, especially strength and conditioning training. Further, the typical growth pattern is nonlinear meaning that during the youth and adolescence, different growth spurts occur [7]. Girls often have their first real growth spurt at the age of 13, while boys on average have their growth spurt at the age of 15. During these spurts, the adolescent can grow several centimetres in a short period. Normally, during these growth spurts, the skeleton grows faster than the tendon and muscles, and hands and feet are the anatomical areas that grows first, and during these spurts, the players are more susceptible to overuse injuries [8, 9]. Thus, monitoring growth in young players to adjust the training load during these growth spurts is recommended.

40.2.2 Handball Profile Schools and Sport Specialisation

Even though there are no studies on handball, several studies in other sports have shown that early (i.e. preadolescence) sport specialisation is associated with an increased risk of injury [10]. To our knowledge, there are no specific guidelines for the training volume in youth handball. Guidelines from other sports suggest that youth athletes should not spend more hours per week than their age playing sport; they should avoid specialising in one sport before adolescence and should have at least 1 day per week off from training [11]. However, as mentioned earlier, players from the same chronological age may vary in biological age, and therefore two players from the same team may vary in terms on the amount of training load that they can cope with. Many elite adolescent players are enrolled at handball-profiled secondary schools or academies from the age of 15–16. A recent study showed that Swedish elite players, aged 15–19, enrolled at handball-profiled secondary schools on average train handball and strength and conditioning 13 h a week during a competitive season. However, there is a large variety within this group, ranging from 8 to 23 h per week [5]. Enrolling a handball-profiled secondary school often increases the handball load since handball practice is also performed during school hours, in addition to the training and matches that the players do with their club team. This is a critical period since not only does the handball load increase from one season to the other but also that these increases of handball load normally happens right after a long summer break.

Further, entering secondary school does not only mean an increase in handball load but also in potentially other "stressors" [12]. For some players, this also means moving to a new city and living by themselves. Additionally, the player may feel that they have to show that they deserve the place and gain the trust from a new coach. On the other hand, a handball-profiled school often facilitates the ability to monitor training load and provides an opportunity for the player to develop as a handball player. If the team coach and the handball instructor at school are not the same person, it is crucial that they communicate to optimise training periodisation, rehabilitation, etc. for the players.

40.2.3 Returning to Handball After an Injury

When returning to handball from an injury, there is a potential increase in injury risk due to the rapid increase in training load, especially in a long-term absence from the sport. When returning to a sport regardless of injury, the injured tissue must be fully repaired as well as prepared to the load that will be put on the tissue. The adaptation and preparation to this load are established during the final phase of the rehabilitation. Moreover, one must also consider that other body regions have not been exposed to the demands that come with handball during the injury and rehabilitation period, and gradually exposure to this load is needed. A typical example is when the player returns from an ACL injury or long-time ankle injury. During the rehabilitation period, the player has not made any heavy throws, especially jump throws, due to the impaired knee or foot control and the lack of optimal power transition from the lower extremity to the shoulder. Therefore, a throwing programme with a gradually increased frequency of heavier and heavier throws and jumps throws is recommended not only for shoulder injuries but also in all injuries that limits the player from maximum throwing for more than 3 weeks. One more consideration is that during a long-time injury, the youth and adolescent players have likely grown more or less which is something that will affect their motor control and, therefore, potentially could need additional time to adapt to these changes. When returning to play, a stepwise strategy is recommended, where the player is gradually exposed to more and more handball load, e.g. initially only participates in half of the training session or only half of the game.

40.2.4 Playing with Older Players

Playing with a team of older players and injury risk is something that is debated frequently. There is no support that playing with a team of older players would increase the risk of injury in youth and adolescent handball. However, older players are often bigger and faster, and the game is often more intense so the risk of especially traumatic injuries could potentially be higher. But as mentioned before, if the player is biological matured and physically prepared for it, the risk of an injury should not be increased. If the player train and competes with several teams, e.g. the team of their own age and one or more teams with older players, there is a potential risk of overloading. Then there is a potential risk of not getting adequate recovery from each session or playing too many matches in contrast to training. The latter is important since there is a much higher risk of an injury during competition but also since the amount of training at this age is very important and reducing training hours in benefit for competition could lead to underdevelopment of the physical fitness that is required later on in the player's career.

40.2.5 Change of Ball Size and the Introduction of Wax/Glue

One other debated scenario is when the player changes ball size or starting to use wax or glue and its relationship to especially shoulder injuries. The handball size and weight are regulated to fit each age category. The following ball size is used for the different age categories:

IHF size 3: Male and male youth aged 16 and over, 58–60 cm in circumference and 425–475 g in weight.

IHF size 2: Women, female youth aged 14 and over and male youth aged 12–16, 54–56 cm in circumference and 325–375 g in weight.

IHF size 1: Female youth aged 8–14 and male youth aged 8–12, 50–52 cm in circumference and 290–330 g in weight.

If the player is used to throw a ball of a certain size and weight and then change ball size in combination with an increased frequency of throws, there is a potential risk of overuse injuries. Even though there are no studies that have investigated whether a change in ball size or weight increases the risk of injuries, a recent study found that if the ball weight is increased or decreased by 20% or more, the throwing mechanics changed significantly [13]. Another potential risk moment is when the players are allowed to use wax or glue, which is introduced in competitive games around the age of 15 to 17. By using wax/glue, the players are able to grip the ball better and throw harder and also throw with different techniques. Further, the handball used in young players is about 87% of the size of handball used in seniors. But, the young players have about 77% of a senior players' hand size [14, 15]. However, there are no studies to this date that have investigated the relationship between change in ball size or the introduction of glue or wax and injuries.

40.3 Training Load Definition and Its Matter in the Young Player

Training load can be defined as the load that is placed on the player in both training and competition [16]. The research on training load and its relation to injuries in younger athletes is in its early stages, and most of the research is done on baseball, cricket, football and rugby. Measures of training load can broadly be divided into external and internal training load [6]. External training loads are objective measures of the training performed by the player, for example, speed or distance covered, the number of throws or as described above the number of weekly training and competition hours.

Internal training loads may be defined as biological stressors (both physiological and psychological) stressors [16]. Typical internal training load measures are heart rate or session rating of perceived exertion (RPE), where the player provides a 1–10 rating on the intensity of the session. This score is then multiplied by the duration of the session to calculate a training load (RPE score × minutes). It is recommended to use internal and external training loads in combination to provide greater insight to training stress [16].

As mentioned before, training and match load under optimal circumstances will lead to an increased physical fitness, thus readiness for sport and increased performance. Something that is most necessary in the development of the young player. However, the training load can also be too high, with no adequate recovery time or a too fast increase in training load, which could lead to overtraining, fatigue and injuries. High training load, in terms of absolute number of pitches and training hours per week, is associated with a higher injury risk in youth baseball pitchers, especially overuse injuries [17–19]. The same association is seen in youth cricket [20, 21].

On the other hand, low training loads, i.e. reduced training volumes, have also been associated with a higher risk of injuries [22], which could be explained by the fact that the athlete is not prepared for the load that is put on the body at a specific time.

A drawback to the use of absolute load changes is that this approach does not take the players' changing cycling of injury, participation and other non-modifiable risk factors into account. For example, there is a possibility that the recommendations of the number of throws might be different at the beginning of the season than in the mid- or end-season. In addition, the number of throws tolerated is likely to be different for experienced players compared to inexperienced players or when a player returns to sport after injury. To encompass these changing factors, relative training load changes are likely to provide a more applicable measure of the external load.

Sudden increases in training load (acute training load) relative to the 4 preceding weeks of training load (chronic training) have been suggested as a feasible way to calculate relative training load changes in sport [6]. This approach provides a more specific individual comparison of training

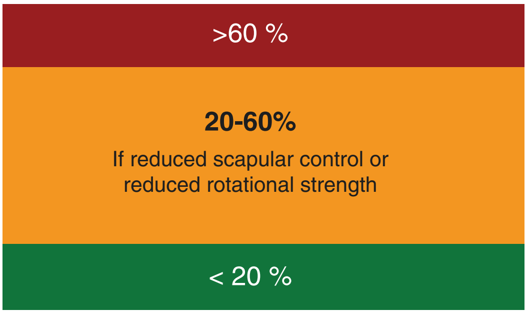

Fig. 40.1 Sudden increases in the weekly handball load (total amount of training and match hours) compared to 4 weeks preceding average of handball load is associated with shoulder injuries the following week. Green zone: Low risk for shoulder injury, despite reduced scapular control or external rotational strength. Yellow zone: Risk for shoulder injury if the player has reduced scapular control or external rotational strength. Red zone: All players have an increased risk for shoulder injury

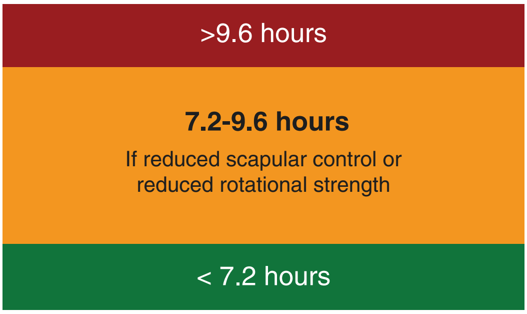

Fig. 40.2 Player A. Player A has a 4 weeks average of 6 h. If player A increases his or her handball playing load in the following week to more than 9.6 h, he or she will have an increased risk for shoulder injury. If player A increases the handball playing load to 7.2–9.6 h and in addition has either reduced scapular control or external rotational strength, he or she will have an increased risk for shoulder injury. If player A increases his or her playing load to no more than 7.1 h, he or she will have a low risk for shoulder injury

load compared to a group average and has been associated with injury in several sports [22]. A similar relationship between rapid increases in handball load (weekly training and competition hours) and shoulder injuries has been demonstrated in youth elite handball players. In this study, players who increased their weekly handball load by 60% or more had twice as high the risk of sustaining a shoulder injury compared to players who did not increase in their weekly handball load above 20% relative to the 4 weeks preceding average of handball load [23]. Additionally, this study demonstrated how other player characteristics may modify the amount of training load changes a player may tolerate before an injury occurs. For example, players with scapular dyskinesis or reduced external rotational strength had a higher risk for shoulder injuries already at a 20–40% increase in their weekly handball load (see Fig. 40.1). This emphasises that knowledge of more variables (e.g. body mass, alignment, diet, sleep, strength) than training load are necessary to robustly identify how much training load a player can tolerate at any given time [24].

As an example with two players aged 16, player A has 10 training hours per week, while player B has 15. In this case player B trains 50% more than player A. But, if player B has been able to build up the tolerance to this training volume, by having a 4 weeks average of maybe 13 training hours, then 15 training hours a week will not necessarily increase the risk for injury. Instead, it could be more protective to injuries. In contrary, if player A had a 4-weeks average of 6 training hours, a 10-h training week will likely be “too much too soon” as this represents a more than 60% increase in training load. If player A additionally has reduced external rotational strength or scapular dyskinesis, he or she should not play more than approximately 7,5 h the following weeks, because otherwise, he or she will be at increased risk for shoulder injury (see Figs. 40.2 and 40.3).

The reality is naturally often not that “black and white”, but this example can be used to demonstrate the importance of monitoring and to adjust the players training load on an individual basis.

Fact Box
The young handball player needs to gradually adapt to the training load that he or she is exposed to during handball; thus identifying and reducing rapid spikes in training load are crucial!

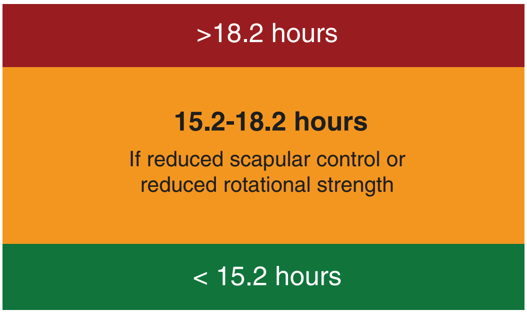

Fig. 40.3 Player B. Player B has a 4 weeks average of 13 h. Player B may, therefore, increase his or her handball playing load up to 18.2 h the following week if he or she does not have either reduced scapular control or external rotational strength. If this is present, he or she may only increase their handball load to between 15.2 and 18.2 h. If player B increases his or her playing load below 15.2 h, he or she will have a low risk for shoulder injury

As mentioned above, knowledge regarding the association between training load and all injuries in handball is sparse. However, this association is likely not unique for shoulder injuries.

40.4 How to Monitor Training Load in Youth Handball

There are several ways to monitor training load in handball, some more technical, time- consuming and costly than others. In handball, the content of one training session may differ largely from time to time. For example, a goalkeeper training session involves a much greater amount of handball throws for the field players, than a more tactical training session. Application of an objective throwing and passes-specific monitoring tool that enables individual monitoring of the number of throws and passes may, therefore, provide a more detailed understanding of the external handball load and subsequent shoulder injury.

Fact Box
High training volumes are not necessarily bad, in fact it could protect against injuries. It is how you get there that is important.

To date, no valid measures have been produced for monitoring handball-throwing load. In comparison to baseball where it is quite easy to measure number of pitches and also the velocity of each pitch, monitoring handball throws is more challenging. It is easier during the matches, and several studies have reported the average number of throws done in youth and senior games [25–27]. During training, it is much harder given that the number of throws is much higher during training than a match and that several players are throwing at the same time. Video analysis of each practice could be performed but is often very time-consuming since each throw of every player often has to be counted manually. As an alternative, several novel gears exist for measure arm acceleration, number of throws and the velocity of each throws. This is regularly used in other throwing sports such as baseball and cricket [28], but the evidence of such monitoring in handball is sparse even though it looks promising.

Although there are many costly and time-consuming measures, which are rarely applicable in youth handball clubs, monitoring the handball exposure does not have to be expensive or comprehensive. In contrast, it can be done quite feasible and reliable. One easy way is to use weekly diaries where the player reports the number of training hours and match minutes. Today there are several smartphone applications to use, and short text message service (SMS) has been shown to be reliable with a high compliance in youth and adolescent players [23, 29–32]. Even though these weekly reports do not measure training load concerning handball intensity or number of throws, it gives a picture of the weekly handball training load put on the player and can easily be used to calculate chronic and acute training load ratios [23]. RPE on a 1–10 scale as described earlier, or other ways to measure perceived intensity, like using “smiley icons” representing light, moderate, intense and very intense sessions, could be recorded in the same way after each training and competition session [29]. Additionally, such an approach may pose a potential risk of overwhelming the youngest players with questions and procedures, which could result in player fatigue or players reporting inadequately to the questions. Therefore, monitoring training load in the youngest handball players requires careful consideration. There is no need to collect a lot of data if there are not enough resources or intention to adequately analyse and use that data.

It is also important to realise that there is a huge difference in a 12-year-old player who plays handball for fun in addition to three other activities compared to a 17 years old player, enrolled to a handball-profiled academy with a full focus on handball and a goal to play for the national team. This difference needs to be recognised when it comes to measuring training load. In the younger player, monitoring training and match load in addition to some basic preseason test could be sufficient. For the older elite player aiming for the national team, more comprehensive measures could be necessary.

40.5 Potential Factors That May Affect the Training Load

40.5.1 Preseason Screening

As described previously, other factors may influence how much training load a player can tolerate before an injury occur. Therefore, it may be relevant to do some preseason screenings and tests to assess aerobic and anaerobic fitness, general strength, power, speed, handball-specific agility and history of previous injuries (Table 40.1). These tests serve the purpose of base values and provide the coaches and medical staff an objective status of the player's physical fitness. These test values also serve as a reference during rehabilitation and return to the sport after an injury. Regardless of which tests that are used, they should be reliable, valid and handball relevant. The preseason screening should also include a history of previous injuries and training routines. This is to estimate what levels of training load the player is used to and tolerates. This is extra important when new players join the team. If applicable, it is relevant to repeat these screening tests at least once in season.

40.5.2 Other Components to Monitor

During the youth and adolescence, both adequate sleep and nutrition are very important, not only for growth but also for injury prevention. Adolescent athletes who do not reach the national recommendations of 8 h of sleep per day or do not meet the nationally recommended intake of nutrients, i.e. a fruit or vegetable intake at least once a day and a fish intake at least twice a week, have a higher risk of sustaining an injury [33]. Both sleeping habit and food intake can be collected via self-reported questionnaires as describe above. However, it depends on the resources and the ability to use the collected data. Questions about sleeping and eating habits should at least be included in the preseason screening to identify players that do not reach national recommended levels.

Fact Box

Measuring other factors than training load, e.g. sleep, strength, nutrition and psychological factors, is important, as these factors may influence the increase in weekly handball load a player may tolerate before injury occur.

Examples of preseason screening and monitoring of training load in young handball player are presented in Table 40.1.

40.6 Critical Periods During the Season

During the youth handball period, there are several critical periods where a rapid increase in training load may occur and could be an issue. In general, as described above, any spikes in training load could lead to an increased risk of injury. In addition there is also a relationship between growth spurt and injuries. Therefore a well-

Table 40.1 Screening measures and monitoring workload in the young handball player

Measures	Equipment	Frequency	Comment
Shoulder strength and shoulder ROM	HHD, inclinometer	Preseason or when a new player joins the team	Should be tested preseason for reference values of the individual player. These values are used both to identify the level of physical fitness of the player and to use as reference values during rehabilitation of a future injury. In the older elite player, these measures can be taken several times during the season to check the players capacity
Aerobic and anaerobic fitness, general strength, power, speed, handball-specific agility	VO_2 max tests; strength tests; jump tests; sprint tests, e.g. bench press; deep squats; clean and jerk; 10-, 20- and 30-metre sprints; CMJ tests; etc.	Preseason or when a new player joins the team	Should be tested preseason for reference values of the individual player. These values are used both to identify the level of physical fitness of the player and to use as reference values during rehabilitation of a future injury
History of current and previous injuries and rehabilitation of these	Self-reported paper form or online questionnaire	Preseason or when a new player joins the team	It is important to identify any current and previous injuries and any stressors that contributed to those injuries
Sleep and nutrition	Self-reported paper form or online questionnaire	Preseason	To identify players that is at risk of not reaching recommended levels of sleep and nutrition. In the older player, this could be measured several times during the season to identify any seasonally risk periods. This could also change during different growth periods, why several measurements during the season are recommended
Training hours	Self-reported dairy, weekly SMS, online questionnaire or smart phone application	Reported every week	In the younger player, the coach or parent can report the workload to minimise the risk of overwhelming the player with weekly questions
Match minutes	Self-reported dairy, weekly SMS, online questionnaire or smart phone application	Reported every week	In the younger player, the coach or parent can report the workload to minimise the risk of overwhelming the player with weekly questions
Training intensity (RPE)	Self-reported dairy, weekly SMS, online questionnaire or smart phone application	Each training session or each week	Monitoring the training and match time will provide a total workload but not the intensity. RPE is one way to measure the intensity; however measuring RPE is more suitable for the elite adolescent player enrolled at handball-profiled academy than the younger player

CMJ counter movement jump, *HHD* handheld dynamometer, *RPE* rating of perceived exertion

planned season regarding periodisation of the training and competition is cruciate. This can be easier said than done since some of these factors are harder to modify, e.g. match and tournament schedules, other sports that the players participate in, etc. Nevertheless, there are some general periods during the season that requires extra attention. A summary of these potential overload scenarios and how they may be addressed are presented in Table 40.2.

40.6.1 Transition from Off-Season to On-Season

The youth and adolescent players often have longer off-season periods during the summer compared to the senior players, resulting in a longer period with off-court training. Going from an off-season to on-season, i.e. on-court season, generally, results in increases of side-cutting movements, short rushes and heavy handball throws. Further, the player

Table 40.2 Scenarios in youth handball with potential risk of overload issues

Scenarios	Potential issues	Examples of typical injuries seen youth handball	How to address these issues
On-season to off-season	Going from on-court to off-court running	Medial tibia syndrome, runners knee, other lower limb overuse injuries	Gradually adapt the player to running on off-court surface
Off-season to on-season	Increased throwing, jumping and side-cutting movements	Throwing related shoulder problems, hip problems, groin problems, patellar tendinopathy and traumatic knee and foot injuries	Off-season throwing programme with gradually increased frequency and velocity. Continue neuromuscular training and side-cutting and jumping movements during off-season
Tournaments, training camps and try-outs	General rapid increase in workload, both physical and psychological	Throwing related shoulder problems, patellar tendinopathy, traumatic knee and foot injuries. General risk of non-functional overreaching due to no adequate recovery	Plan for the increased acute workload by increasing the chronic workload or avoid tournaments during periods of low chronic workload
Returning to sport after an injury	The injured tissue needs to be fully recovered and prepared for the handball demands. Further, some handball-specific parts, e.g. high velocity throwing might have been neglected during the rehabilitation	Reinjuries of the same anatomical site. Throwing related shoulder problems	When returning to sport, this should be done gradually, e.g. playing half of the first game. Also, returning from a long-term injury, player needs to gradually adapt to the workload
Enrolling to handball-specific education programmes	A general increased handball workload, both number of training sessions and the intensity of the sessions. Also, psychological stressors, e.g. starting a new school, new coach, moving to a new city	Throwing related shoulder problems, jumpers knee, traumatic knee and foot injuries. General risk of non-functional overreaching due to no adequate recovery	Identify components that are new to the player or most likely to be increased (frequency and intensity) and specifically prepare the player for these

needs to get used to the court surface and indoor shoes again. This leads to a potentially increased risk in both acute and overuse injuries.

40.6.2 Transition from On-Season to Off-Season

The same can be seen in the transition to an off-season where the player is going from more on-court training and competitions to preseason training, e.g. gym workouts and off-court running, which could potentially increase the risk of overuse injuries due to change of surface.

40.6.3 Tournaments, Boot Camps and Regional/National Team Try-Outs

Preseason tournaments and training camps are common in youth handball. During these tournaments and training camps, the acute training load is often high. Especially when taking into consideration that in youth handball, these tournaments and training camps often take place in periods when the chronic training load is low, e.g. during the summer break or just in the beginning of the season. In addition, at these camps and tournaments, it is not only the number of practices and matches that increase but also the intensity of each session. A case report of a young handball player with shoulder problems and her training and match load as elite youth player is presented in Box 40.1 and Fig. 40.4 (see Box 40.1 and Fig. 40.4).

Box 40.1 Case Report of a 13-Year-Old Handball Player with ShoulderProblems

History

A 13-year-old girl presented in October with shoulder pain of approximately 2-month duration. More comprehensive questioning revealed that the subtle pain began 5 months ago during the spring season (April) and gradually increased with more substantial problems during a summer camp in August. Since August she tried to keep playing, but the pain got worse and worse and now she can't throw anymore. Her pain is located posteriorly of the shoulder during cocking phase. No trauma to the shoulder except what comes with handball. She did not seek care until now and tried to push on because there were try-outs for the regional team and she wanted to impress the new coach. She is a backcourt player, tall for her age and throws hard for her age. According to herself confirmed by the parents, she reaches the sleeping and nutrition recommendations, and she is healthy otherwise.

Training during the competitive season: four to five training sessions per week, three times with the U13 team and two times with the U15 team. Two times per week, the training sessions are longer than 2.5 h. Most training sessions are focused on on-court handball practice, and not that much strength and conditioning training is done on regular basis. Two to four games per week, one to two games with the U13 team and one to two games with the U15 team. She does not participate in any other sports except for school gymnastics (two times per week).

Training during the summer season: three to four training sessions of which one is on handball court and the rest is strength and conditioning and two summer tournaments otherwise not much heavy throwing for 2 months. Second week in August, she participated in a summer camp, with two on-court handball sessions per day.

Clinical Findings

Identical pain is provoked during the apprehension test, but no sensation of instability. Resisted ER in 90–90 position is also provocative. Resisted ER in 0–0 position is pain-free, but she is significant weaker compared to the non-dominant side. Total ROM is 10° less in the affected shoulder. Shoulder tests for labral and biceps pathology are unremarkable. An MRI of the shoulder was performed a week before the consultation and revealed nothing extraordinary.

Therapeutic and Rehabilitation Focus

The rehab should initially focus on resting the shoulder from throwing and then gradually build up shoulder strength and then gradually return to heavy throwing. Also, increasing the ROM of the affected shoulder is important. Further, it is important to discuss the match/training ratio and the ratio between handball-specific training, i.e. throwing and strength and conditioning, with the player and the parents in this case. Also the long training sessions should be considered. Finally, to prepare for the workload during the summer camp and the beginning of the season, especially throwing workload, she will get a throwing programme to perform during the summer season, with gradually increased velocity and frequency.

Summary

This is not a unique scenario for a youth elite player. In this case there are numerous factors that could have contributed to the development of shoulder pain; the ratio between match and practice during the season, the >2 h training sessions, the ratio between handball training and strength and conditioning and also neglecting the minor shoulder problems during the spring. But the most obvious issue is the rapid increase in workload and especially throwing load, when going from summer leave to summer camp. When taking the patients' history, it is important to ask about all these factors to get the whole picture and to identify any potential stressors. Figure 40.4 illustrates the total handball load (match and on-court training) for this player during the summer break to the beginning of the competitive season (May to September).

40.7 Summary

When looking at all the aspects described above, it is easy to understand that overload issues in youth handball are multifactorial and several aspects need to be considered. It is also important to understand that many of these factors are dynamic due to that the player goes through several growth and maturing phases during these years. The general principle, regardless whether it is general or a specific training load, is to let the player gradually adapt to that exposure. With a physically challenging sport as handball comes a risk of injuries, and reducing the risk of injuries to zero is probably not possible. But with all the knowledge that we have today regarding the impact of training loads on, especially overuse injuries, the goal should be to do the best as possible to reduce them. Finally, and most important, handball should be fun, exciting and challenging for the young player. With those ingredients comes development.

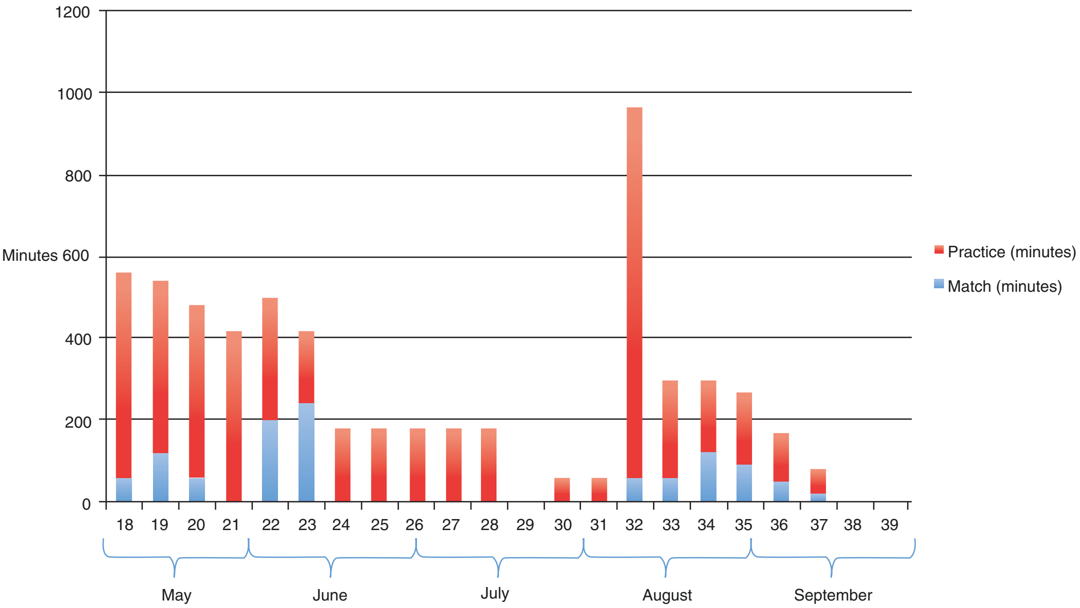

Fig. 40.4 Total handball playing load on a 13-year-old handball player during the off-season and precompetitive season

Fact Box
When monitoring workload in young handball players, use reliable and valid measures and only measure things that will come to use.

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Perceptual Expertise in Handball

41

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41.1 Perceptual Expertise in Handball

Excellent performance in handball depends on an optimal integration of both motor and sensory skills, the latter being especially related to visual perception and cognition. To illustrate, *field players* must not only be able to throw a ball with accuracy and good speed, but they must also be able to spot the optimal moment during play, for example, when throwing towards the goal, alternatively play a pass to one of their teammates or change position to open new scoring opportunities for teammates [1–3]. Likewise, without doubt *goalkeepers* need to bring in the physical skills required to successfully prevent an opponent from scoring a goal, but considerable time constraints acting upon goalkeepers necessitate that they also time their defensive actions optimally to be at the right place at the right time [4, 5], for example, through anticipating what the opponent is about to do next [6, 7]. Further, *coaches* must carefully observe the game as it unfolds, which includes monitoring the various players' behaviours on the field, identify any possible deviation from the match plan or see the necessity to change strategy due to the current match situation and decide about when and how to make appropriate coaching intervention [8, 9]. Finally, and of equal great importance, *referees* are required to carefully monitor the players' moves, identify any deviation in players' behaviour or specific game situations from the rules of handball and based upon such identification select and communicate the optimal consequence to the players, all within a short moment of time [10, 11].

Over the past decades, a vast body of research has accumulated suggesting that exceptional performance in the above illustrated situations is associated with well-developed task-specific perceptual-cognitive skills [12, 13]. Here, we review and discuss the empirical evidence available from the handball literature so far that relates to the aforementioned four groups of actors—goalkeepers, field players, coaches and referees. As will be clear from the following sections, considerable effort has been invested in examining and understanding goalkeepers' perceptual-cognitive skills; however, comparatively less is known about these skills in the other three groups. In this regard, we hope this chapter encourages intensification of efforts in investigating perceptual-cognitive skills as one factor deemed relevant, among others, to different actors' performances in handball.

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41.2 Perceptual Skills of Goalkeepers

Handball goalkeepers face severe time constraints when required to intercept a ball being thrown towards them. For example, a ball thrown from a 7 to 10 m distance with 100 km/h reaches the goalkeeper in only 280 ms or 400 ms, respectively [14]. Even if thrown with 'only' 60 km/h from the same distances, ball flight time between thrower and goalkeeper is between 420 and 600 ms. These exemplar figures become more impressive when the latency in the processing of visual sensory input into motor commands up to movement initiation and the time it takes to complete a move in one particular direction are considered further (e.g. bottom left corner of a goal). From these aspects it is obvious that goalkeepers need to develop strategies to reduce the costs associated with the time constraints so as to preserve the chance of successful interception [4, 15]. One potential strategy is to anticipate the outcome of a player's throw and, based upon this, to timely initiate a response and move into the predicted direction prior to ball release [16]. The majority of research examined goalkeepers' anticipation in the 7 m penalty situation. This focus is reflected in the following sections where basic methodological approaches used will be described alongside the key findings, for example, on expertise differences in the ability to effectively read an opposing thrower's action intention.

41.2.1 Methodological Approaches and Expertise Differences: When and What Do Skilled Goalkeepers Perceive?

As pointed out before, handball goalkeepers need to decide early about where to move in order to preserve the chance of successful ball interception. One strategy to address this task is to closely observe an opposing player's movement and search for predictive kinematic cues. In this regard, a first question relates to *when* in the course of an opponent's action goalkeepers are able to predict action outcome better than chance and whether differently skilled goalkeepers differ in the ability to make early correct predictions. A means to experimentally address this question is to present goalkeepers with videos of an opposing thrower's action recorded from a goalkeeper's perspective and to ask them to predict the outcome of throws as accurately as possible (see Fig. 41.1a). To force participants into real anticipation and not just mere reproduction of what was presented in a video, ball flight information is withheld from the videos by stopping the clips prior to or at the moment of ball release and turning the screen black (*temporal occlusion paradigm*) (in handball see, e.g. [4, 5]). Using different temporal occlusion conditions (e.g. −160 ms before ball release up to ball release; [6]) reveals that anticipation gets better when the later videos are occluded. More interesting though is that skilled goalkeepers are particularly superior to less-skilled or novice goalkeepers in making correct predictions at early occlusion conditions (for reviews see, e.g. [12, 13]). This superiority may enable skilled goalkeepers to timely select an appropriate response and allow being at the right place at the right time [4].

Fact Box

Skilled handball goalkeepers *as opposed to* less-skilled or novice goalkeepers:

Are superior in correctly anticipating an opposing thrower's action intention based on early kinematic cues provided by his or her movement

Seem to rely on globally distributed kinematic cues (e.g. ball, throwing arm, trunk) when inferring an opposing thrower's action intention.

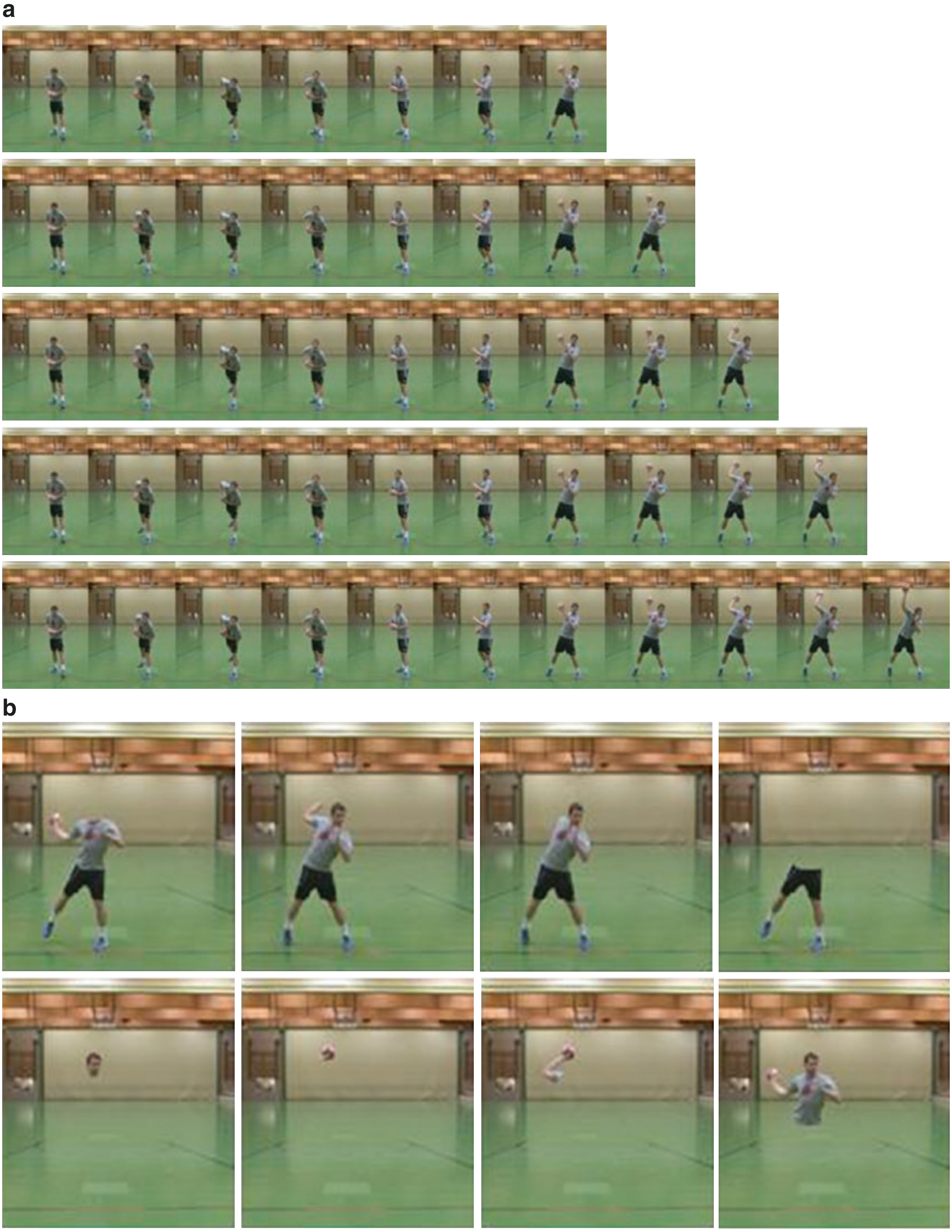

Fig. 41.1 Illustration of the (**a**) temporal occlusion paradigm and (**b**) spatial occlusion paradigm as used by [6]. In (**a**), occlusion conditions range from 160 ms prior to ball release (top row) in 40 ms steps up to the moment of ball release (bottom row)

Moving further, another question relates to *what* kinematic cues do goalkeepers use or rely on when making anticipatory judgements. At least two methodological approaches are possible to address this question. The first solution refers to the *spatial* (or event) *occlusion paradigm*. Using this paradigm, selected regions of an opposing player's body (e.g. throwing arm, trunk, head) or the ball are withheld from a video or presented in isolation (see, e.g. [6]; for an illustration see Fig. 41.1b). Participants are asked to predict action outcome, and accuracy achieved under different spatial manipulation conditions is later compared, among others, against the control condition (i.e. no spatial manipulation) as well as relative to chance level (e.g. 50% if there were two response options). Loffing and Hagemann [6] used this methodology to investigate skilled and novice goalkeepers' reliance on different kinematic cues when asked to anticipate the type of shot (i.e. hard vs. soft shots) in 7 m penalties occluded 40 ms before ball release. The authors found that, relative to the control condition, skilled goalkeepers suffered more from the removal of the 'throwing arm and ball' area and the upper body compared to novice goalkeepers. Conversely, skilled but not novice goalkeepers improved accuracy with more bodily regions of a penalty-taker being available and demonstrated performance similar to the control condition only when all body parts above the hips were visible (i.e. trunk, shoulders, arms, ball and head). Taken together, skilled goalkeepers seem to rely on a more 'global' perceptual strategy by picking up and integrating cues from different distal and proximal body regions into anticipation (see also [17]).

A second solution to approach the question of what kinematic cues goalkeepers use is to record their *eye movements*, for example, while they aim to intercept an opposing player's throw (e.g. [4, 5]). In eye-tracking research, the gaze parameters of interest often include the number of fixations, fixation duration, the relative duration of fixations towards specific body regions of an opponent (e.g. a penalty-taker's head or throwing arm, ball) and the transition of gaze between different fixation regions (for a meta-analysis on expertise differences in gaze behaviour, see, e.g. [18]). The relative duration of fixations towards specific body regions serves as an indicator of the regions' potential relevance for making predictions. Long fixation on a particular region is suggested to indicate high relevance as opposed to regions that are rarely fixated on.

Eye-tracking research in handball goalkeeping is rare. In one of the few studies, Schorer [4] used a mobile eye-tracking device to examine the gaze behaviour of eight expert, four intermediate and five novice goalkeepers, while they tried to intercept handball penalties presented as videos on a large projection screen. Expert and novice goalkeepers were found to primarily fixate a penalty-taker's head and the ball/hand area, whereas intermediate goalkeepers directed their gaze less often to the head. Across groups, gaze was very rarely directed towards lower parts of a penalty-taker's body. Overall, these findings add to the intuitive assumption that task-relevant information appears located in the upper body of an opposing thrower; however, distinct expertise differences in gaze strategy were not confirmed. It is important to note that gaze recordings do not provide a perfect representation of an observer's actual allocation of attention to particular regions ('looking vs. seeing', [19]) and that focussing on the identification of 'optimal' gaze patterns may run the risk of neglecting intra- and interindividual differences in gaze strategies [20]. Given the paucity of eye-tracking research in handball goalkeeping, clear-cut conclusions on expertise differences in gaze strategies or empirically driven recommendations for instructing goalkeepers where when to look at in order to improve anticipation cannot be properly made yet.

41.2.2 A Special Case: Anticipation of Left- and Right-Handed Throws

Handedness is an issue in handball. Coaches strive to have right- and left-handed players in the team to fill, for example, the two field positions on the left and right (backcourt and wing) with these players [21]. The rationale behind is that opportunities to score from these positions are better (e.g. due to better shooting angle) for left-handed (right-handed) from right (left) field positions. Therefore, a minimum of two out of seven players (six field players plus goalkeeper) of a team, at least at the professional level, can be expected to be left-handed [22]. While this would mean that left-handedness is more common in handball than in the normal population (~ 10%; [23]), it still is clearly underrepresented compared to right-handedness.

The relative rarity of left-handed players might provide them with an advantage in situations such as the 7 m penalty. As tentative support for this claim, Lobinger et al. [24] found that, at the European Handball Championship 2010, 43.18% (133 out of 308) of successful penalties were thrown left-handed. Similarly, Loffing et al. [22] reported that the frequency of left-handed players among the top goal scorers of the handball World Championships 2005–2015 ranged from 25.64 to 44.44%. Both findings indicate that the percentage of left-handers successful from the penalty mark tends to exceed the proportion of left-handers expected to be on the teams (~ 28.57%; i.e. two out of seven), suggesting a possible performance advantage for left-handers in the penalty situation.

One mechanism assumed to underlie such potential advantage is that goalkeepers face difficulties anticipating a left-hander's action intention due to low familiarity with relatively rarer left-handed throws. Indication for better anticipation of right- than left-handed actions has been demonstrated in different sports including handball [22], tennis [25] or volleyball [26, 27]. An important methodological step in this line of research is to present actions in both original and horizontally mirrored orientation (see Fig. 41.2 for an illustration). For example, an original left-handed throw towards the top right is also presented as a right-handed throw directed to the top left. Doing so eliminates potential individual differences in original left- vs. right-handers' movements and allows proper attribution of differences in anticipation accuracy to an opponent's handedness. Using such protocol [22], handball goalkeepers and non goalkeepers were found to be more accurate in predicting the exact corner and side of goal (i.e. left vs. right) of right- than left-handed penalties. For the prediction of height (i.e. top vs. bottom), a descriptive trend in the same direction was found. Interestingly, the handedness-related difference in prediction accuracy was

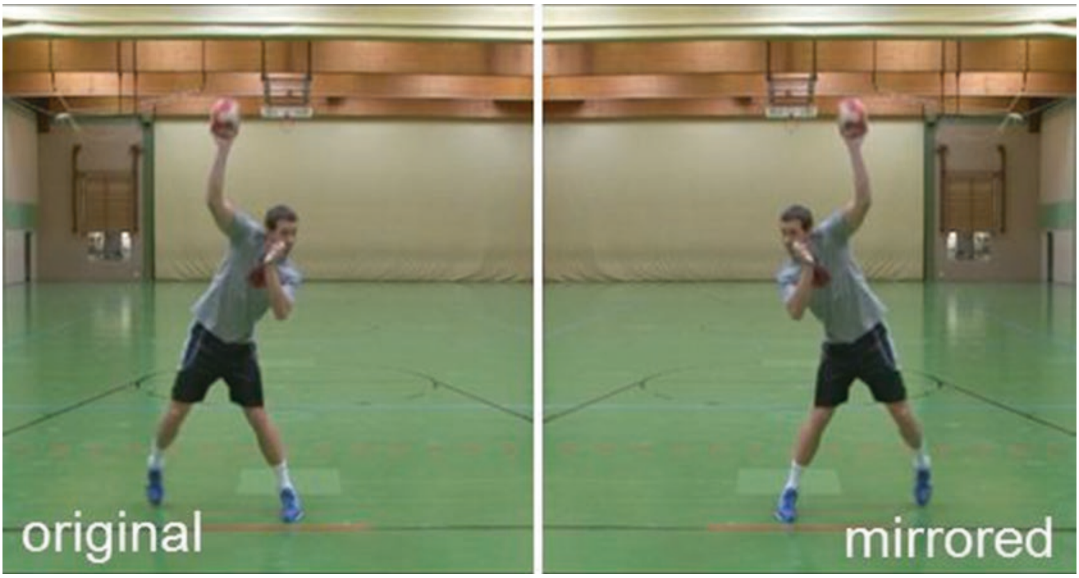

Fig. 41.2 Screenshot of a video frame (moment of ball release) in original and horizontally mirrored orientation as used in research on handedness effects in handball goalkeeping [22, 28]

not accompanied by differences in gaze behaviour. Albeit findings should be considered preliminary, goalkeepers may adopt a similar gaze strategy against right- and left-handed throwers, but they could be less capable of picking up and interpreting the anticipation-relevant kinematic cues provided by left- as opposed to right-handed throws. Furthermore, both left- and right-handed observers seem to have difficulties anticipating left-handers' actions [25], indicating that hand-specific visual experience (i.e. primary exposure to right-handed actions) rather than hand-specific motor experience (i.e. ability to throw either left- or right-handed) drives the handedness effect. On a positive note and supporting the notion that visual experience is important, hand-specific perceptual training (e.g. exclusive training against left-handed penalty-takers) was found to help counteract novice goalkeepers' reduced anticipation skill against left-handers [28].

Fact Box

Skilled handball goalkeepers *and* less-skilled or novice goalkeepers:

Appear to have difficulties anticipating the outcome of left-handed throws

May be similarly inclined to include knowledge about an opposing thrower's action preference into the prediction of his or her action outcome

Have not (yet) been confirmed to use considerably different gaze strategies when observing an opposing player's throw.

41.2.3 The Role of Contextual Cues

The previous sections focussed on goalkeepers' ability to read an opposing thrower's intention based on his or her kinematics. Kinematics, however, is not the only information source goalkeepers may base their predictions on. Likewise, non kinematic cues, also referred to as contextual cues, and the future event probabilities associated with these cues may be integrated in the dynamic process of anticipation [16, 29]. This proposition is primarily based on findings outside handball, suggesting that factors like an opponent's on-court position [30–32], previous action outcomes [33, 34], base rates of certain events [35, 36], game score [37, 38] and repeated exposure to a particular opponent [39] or action [40] affect skilled anticipation.

In handball, Gutierrez-Davila et al. [7] compared the impact of two different conditions of a priori information about shooting direction on highly skilled goalkeepers' anticipatory strategies for interception of balls thrown from a 10 m distance to the goal line. In one situation, goalkeepers were informed that the throwers would direct the ball to the bottom or top corner on the side of their throwing arm (i.e. two goal corners as target areas). In another, more uncertain condition, goalkeepers were told that throwers could direct the ball to any of the four corners of a goal. Analyses of the timing of goalkeepers' lateral response initiation relative to the moment of a thrower's ball release revealed that goalkeepers moved considerably earlier in the two corner condition (low uncertainty; $M = -342$ ms, $SD = 71$ ms) compared to the four corner condition (high uncertainty; $M = -193$ ms, $SD = 67$ ms), suggesting that narrowing down outcome alternatives may facilitate timely initiation of interceptive moves.

One strategy that may help reduce uncertainty about a particular thrower's likely action is to consider his or her action preference. In a nicely designed experiment, Mann et al. [41] asked 20 female handball goalkeepers from the first three divisions of the Dutch national handball league to anticipate the outcome of 7 m penalties as quickly and as accurately as possible. Penalties were presented as videos on a notebook monitor occluded 80 ms before ball release. The experiment was divided into three blocks, a pretest, a training phase and a post-test, all run within one session. In the pre- and post-test, unbeknownst to participants one of the two throwers had the preference to direct 75% of shots to the top-left corner (from the goalkeeper's perspective), while the remaining 25% of shots were distributed equally across the other three corners (i.e. 8.33% per corner). The other thrower did not have a preference and directed throws with equal probability to the four corners. During training, goalkeepers were confronted with the same two throwers, and both throwers either had a 75% preference for the top-left corner or no preference. While no feedback on actual action outcome was provided after a trial in the tests, such feedback was given during training. Full factorial combination of the throwers' preferences in tests and training ensured that for half of participants, the thrower with (without) an action preference in training also had the same (no) preference in the tests, whereas for the other half of participants, the thrower with (without) an action preference in training had no (had an action) preference in the tests. Pre- to post-test comparisons revealed that goalkeepers were more accurate and responded earlier against the thrower who had the same action preference in tests and training. Conversely, accuracy declined against the thrower with an action preference in training but not in the tests. No meaningful effects were found for the group of goalkeepers who trained against throwers under the condition of no action preference. Overall, these findings suggest that knowledge of an opponent's action preference may facilitate goalkeepers' performance if an opponent actually acts according to his or her purported preferences. Overreliance on action preferences, however, could turn out detrimental in case an opponent does not behave according to his or her supposed preferences. A recent replication indicates that the assumed facilitating effect of knowledge of opponents' action preferences is not limited to skilled goalkeepers but occurs in novice goalkeepers as well [42].

41.2.4 Interim Conclusion and Perspectives

The key points and best evidence on handball goalkeepers' perceptual-cognitive skills are summarized in Fact Box 1. From a practical perspective, it seems quite intuitive to assume that a thrower's kinematics and information outside a player's movement (e.g. from *where* a ball is thrown towards the goal, *who* throws the ball) is relevant to and guides a goalkeeper's anticipation. Still, empirical evidence supporting these claims is rare in handball. Future endeavours are encouraged to fill this gap, not only to inform theory (e.g. on how kinematic and contextual information is integrated into the process of anticipation; [16]) but also to provide scientifically grounded recommendations, for example, on what additional information players should be given and how it could ideally be communicated [43]. In addition, considering process-tracing measures such as the recording of goalkeepers' eye movements may provide further helpful insight into the perceptual-cognitive processes underpinning skilled anticipation [44].

Beyond the points elaborated on in the sections above, several other issues are of potential relevance to better understand and facilitate the development of handball goalkeepers' perceptual-motor skills. For example, questions relate to study designs such as whether goalkeepers should be tested under coupled (e.g. simulating or actually intercepting a ball) or uncoupled (e.g. responding verbally or via button press) conditions [45], whether the graphical detail of a display affects goalkeeper's motor response [46] and whether virtual reality could provide a useful testing environment [47, 48]. Moreover, quite little is known about age-related compensatory mechanisms in handball goalkeepers' perceptual-cognitive skill as a consequence of deterioration in motor performance [5] or the potential benefit of task-specific perceptual-cognitive training for fostering the development of talented handball goalkeepers [49].

41.3 Deception and Disguise: An Example of an Interaction of Perceptual Expertise and Kinematic Skills in Handball

While considerable research focused on perceptual-cognitive expertise and anticipation as a central element to counteract the informational constraints within sports games, recently the special situation of deceptive action has attracted particular interest. Inevitably, goalkeepers' strategy to foresee action outcome evokes game internal rule-consistent deceptive movement strategies in field players aimed at hindering successful anticipation [50, 51]. In this regard, Jackson and team [52] differentiate between the two basic solutions of disguise and deception:

> In the case of disguise, an actor might attempt to minimise the availability or delay the onset of indicative cues. If effective, an observer would be reduced to guessing so that the minimum level of performance one would expect is chance level. In contrast, the aim of deception is to provide information that misleads or 'fools' an observer into making an incorrect judgment (pp. 356–237).

Accordingly, a *disguise* would result in a neutral version of a movement until the disclosure of the final intent is inevitable but too late for the observer to react on appropriately. In contrast, *deception* means pretending a certain explicit intent to evoke false reactions. As such, the latter resembles the fake or feint defined by Meinel and Schnabel [53] as a movement intended to cause a false reaction with the resultant time disadvantage eliminating the ability to counteract the intended genuine movement.

As is illustrated in Fig. 41.3, given the diversity in movement solutions in handball deceptive and disguised actions may manifest in different ways and be executed either with the whole body or specific body parts (e.g. throwing arm and/or hand). Throw execution may be based on an *alteration* that deceives by suggesting a fake movement at first (e.g. throw towards the top right corner), which is then altered to the genuine one towards completion of a throw (e.g. throw towards the bottom left corner). *Termination* also suggests a fake movement first (e.g. that a throw towards the goal will be performed), but the fake action is terminated (e.g. swinging through with the ball in hand and moving the throwing arm backwards) before the intended action is performed (e.g. actual throw towards the goal). *Disguise*, in turn, involves the above-mentioned provision of neutral information as long as cues associated with the intended action outcome can no longer be hidden from the opposing observer. Importantly, deception (alteration or termination) and disguise are not mutually exclusive, and each can be part of the same action but at different points in time. The present body of research into deception recognition and execution adds on to prior findings focusing on the expert-novice comparison regard-

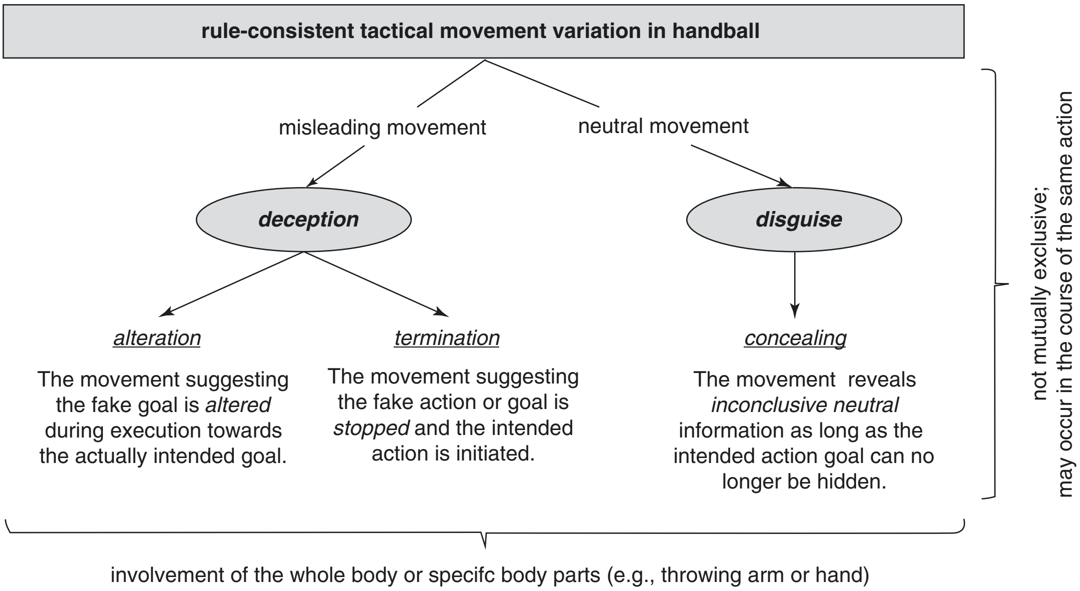

Fig. 41.3 Structural overview on deception and disguise [50–53]

ing performance, information pick-up and underlying mechanisms.

41.3.1 Effects of Deception and Disguise on Perception in Handball

In light of the highly complex running paths and direct interaction with the defence, whole body terminations such as side step running feints are in use in handball. Field players may initiate their running movement by stepping towards the right but interrupting that to pass their opponent on the left side. Accordingly, the displacement of the centre of mass has proven to be a relevant factor [54]. In similar situation research has found the running feints to compromise the prediction accuracy, while skilled participants proved to be less susceptible than novices [52, 55, 56].

The rules of handball also allow terminations within the throwing movement as an example for effector-specific deception (e.g. in the 7 m penalty). In two studies [57, 58], Cañal-Bruland and colleagues referred to a common 7 m penalty throw feint where the throwing movement stops just before ball release to test if experts' superiority in judging deceptive and nondeceptive actions correctly [52, 54, 59] is due to their perceptual or motor expertise. Skilled handball players (assumed to be experienced in deception execution), skilled handball goalkeepers (assumed to have perceptual but few motor experience in deceptive throws) and novices were shown videos of penalty-takers viewed from a neutral side view. Penalty-takers performed either a real throw (nondeception) or pretended to shoot but did not release the ball (deception). Videos stopped at the moment the ball-carrying hand passed the penalty-taker's head, and participants were asked to judge whether the penalty-taker was about to throw or not. Analyses revealed higher judgement accuracy and discrimination sensitivity in skilled groups than novices; however, skilled goalkeepers did not show markedly different performance to field players. Accordingly, from this and related work, clear-cut conclusions regarding the impact of observers' motor and visual experience on anticipation are difficult to make [57, 58], potentially due to the testing of natural groups and corresponding lack of experimental control of these two classes of experience (e.g. see [60]). More relevant though with regard to understanding deceptive action's effect on perception, goalkeepers were found to be biased towards preferentially expecting that the penalty-taker shown in a video was about making a feint rather than a shot. This bias was not found in field players or novices, suggesting that goalkeepers' task-specific experience with the costs when falling for the fake action (e.g. being too late for the true action following the fake) may make them biased towards judging a movement as deceptive [57].

More recently, Helm et al. [61] examined expert handball and novice goalkeepers' reactions under different response conditions. Conditions required either unspecific (i.e. button release) or domain-specific (i.e. moving the hands/feet similar to 'real' goalkeeping) reactions as accurate and fast as possible to a ball presented in a handball goal at different locations (i.e. central or top left vs. right or in one of the four corners). Comparisons revealed that goalkeepers outperformed novices in the domain-specific response conditions only. In yet another test condition, the authors adopted the psychological refractory period (PRP) paradigm by presenting two stimuli in fast succession (i.e. the second stimulus appeared 156 ms after the first) at different locations (i.e. ball top left, then ball top right or vice versa) and asking participants to make domain-specific reactions as fast and as accurate as possible to both stimuli. Helm and colleagues considered this condition deception-like as they assumed it would require participants to reprogram their motor response from reacting to stimulus one to stimulus two. Goalkeepers were found to react faster than novices, and in line with previous PRP findings, reactions to the first stimulus were faster than to the second. Unlike the authors' expectations, however, there was no evidence suggesting that goalkeepers would be faster at switching from reaction to stimulus one to reaction to stimulus two. While not conclusive, Helm et al. speculate that, in reality, goalkeepers may not need to reprogram their actions, and therefore the experiment may not have adequately addressed goalkeepers' actual performance demands.

Besides termination as a form of deception, in handball 'alterations' as another form of deception may occur as well. For example, a thrower might pretend to perform a hard shot towards one of the corners of a goal or hide his or her intention and show a trick shot in the end (e.g. lifting the ball above the goalkeeper's head). With regard to such situation, questions of scientific interest relate, among others, to whether the ability to detect the true action intention varies between observers' skill in handball and which kinematic cues might facilitate action detection. Loffing and Hagemann [6] addressed these questions by analysing goalkeepers' visual information pick-up and kinematic cue usage for anticipation of deceptive (i.e. lobbed shots) and nondeceptive throws (i.e. hard shots). In two experiments, skilled goalkeepers and novices watched videos of 7 m penalty throws recorded from a goalkeeper's perspective, and the participants' task was to identify the type of throw (i.e. lobbed or hard shot). In Exp. 1, the videos were occluded at four progressive time points prior to and additionally at ball release. In Exp. 2, supposable relevant body regions (hand and ball, throwing arm and ball, whole upper body and head alone) were removed or isolated in videos stopping 40 ms before ball release. Results generally reinforced the superior performance of experts over novices in anticipation tasks. In Exp. 1, independent of group performance increased with later temporal occlusion, indicating that kinematic cues available towards the end of the throwing movement are increasingly relevant to correct anticipation of deceptive throws. Furthermore, results from Exp. 2 suggest that ball and hand are relevant for successful differentiation between lobbed and hard throws. However, goalkeepers as opposed to novices seem to additionally require cues from the throwing arm + ball and the upper body, possibly indicating a 'global' perceptual strategy, to demonstrate their full superiority in differentiating between shot types [6].

Finally, another deceptive strategy handball players may generally use to fool their opponent is to present misleading salient cues that are functionally irrelevant to the intended action. For example, a field player may orient his or her head and gaze differently compared to passing or throwing direction, thus generating conflicting social cues in the eyes of an opponent. While scientific evidence on their effectiveness in handball is scarce, in basketball head fakes were found effective in terms of increasing observers' reaction time and error rate in the prediction of action outcome [59, 62–64]. As a final note, given the functional irrelevance of head or gaze fakes with regard to a particular action, in our view these types of fakes constitute a special form of deception that does neither fit into the above-mentioned categories of alteration nor termination.

41.3.2 Kinematics of Deception and Disguise in Handball

Accompanying the research on relevant cues for anticipating deceptive movements, research into deception and disguise additionally applies kinematic research investigating the differences in deceptive and nondeceptive movements [65–67]. In handball, Helm et al. [68] investigated the kinematic patterns underlying deceptive to nondeceptive actions.[1] Five expert handball field players and five novices (all male and right-handed) were instructed to throw at four different targets in a handball goal with a real goalkeeper present. In the nondeceptive condition, participants threw the ball directly at one of the targets. In the deceptive condition, participants were instructed to first 'mimic a genuine throw without final ball release' (p. 310; e.g. to the top left),

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[1] In the original publication, Helm and colleagues labelled the movements investigated as *disguised* movements, not deceptive movements. Here, tying in with the classification provided in the section before, we refer to *deceptive* movements instead because the movements examined correspond to what we would understand as deception by *termination*.

followed by an immediate continuation and repetition of a throw movement that then resulted in a throw at the target on the side opposite to the previously pretended direction (e.g. top right). Players' movements were recorded using 41 retroreflective markers attached to the body plus 8 markers attached to the ball. Application of principal component analysis followed by linear classification of data revealed that classification of actions was more accurate in novices than experts, suggesting less distinct movement features in the latter group. Further, analysis of spatial, but not temporal, dissimilarities between nondeceptive and deceptive throws indicated larger differences in novices than experts. With regard to specific body parts, spatial dissimilarities were largest in the non throwing arm followed by the throwing arm in both experts and novices, and differences increased towards ball release particularly in novices. Findings reinforce the notion from research on action perception that distal and late cues are relevant for movement deception recognition [6]. The high dissimilarities in the throwing arm are consistent with the constraint of the following action parts; that is, to stop the throw or to actually release the ball. The higher dissimilarities in the non throwing arm are supposed to be due to the biomechanical constraint of force absorption prior to the immediate initiation of the genuine action [68].

To date, similar kinematic investigation of alterations in deceptive throws has not been made. However, work by Schorer and team [69] gives initial indication for this step to be vital in investigating deceptive actions. Instructed to throw at targets in the goal as if there were a goalkeeper defending the goal, their expert players' execution of 7 m throws revealed higher functional variability when compared to players of advanced and novice skill. While the study did not explicitly link variability to deceptive vs. nondeceptive movements, the findings reveal a thrower's ability to alter throwing movement while maintaining target precision [70]. Such degeneracy can be seen as basal ability to any deceptive alteration.

41.3.3 Interim Conclusion and Perspectives

The key points and preliminary evidence on deception and disguise in handball are summarized in Fact Box 2. According to a preliminary classification, we suggest to differentiate between deceptive movements with alteration, deceptive movements with termination and disguised movements. The little research on handball available suggests that expert observers (e.g. goalkeepers) are less susceptible to deception and disguise than their less-skilled counterparts. However, as indicated by Helm [67], for example, this finding needs to be examined further in light of domain-specific responses, realistic time constraints or context information dependencies. On the performer side, unlike novices experts appear more capable of keeping deceptive and nondeceptive movements spatially similar until the critical moment of (purported) ball release.

Evidence available so far is promising with regard to developing a better understanding of the impact and mechanisms underpinning deception and disguise in handball. On the other hand, there still needs much to be done both on a conceptual and empirical level. The classification illustrated in Fig. 41.3 should be understood as a suggestion for working towards systematization, if feasible, of deception and disguise. Future empirical work related to perception, kinematics or other performance-relevant aspects in conjunction with practical considerations should follow and test whether the classification proves beneficial in handball and beyond. To conclude with a positive finding potentially helpful to practitioners, perceptual training might help reduce skilled handball goalkeepers' costs occurring when confronted with deceptive movements in the 7 m penalty situation [71]. Collectively, a more profound body of research on deception and disguise may add up to refining and extending perceptual-cognitive (e.g. in goalkeepers) and motor expertise (e.g. in field players) in specialized training sessions.

Fact Box
In deceptive alteration and termination:
Skilled players were found less susceptible than novices in deducing actions when responding after stimulus presentation.
The kinematic cues available late in the course of a movement seem vital for correct discrimination between deceptive and nondeceptive action.
The upper body (e.g. throwing arm, ball and non throwing arm) appears a source of relevant kinematic information differentiating between deceptive and nondeceptive action.
Handball goalkeepers seem to be biased towards preferentially expecting (the first) penalty throw movement as deceptive (termination) rather than nondeceptive.
Expert handball field players are able to keep spatial dissimilarities between deceptive and nondeceptive movements small.

41.4 Perceptual Skills of Field Players

For handball field players, perceptual skills are especially important for their tactical behaviour. As presented in Chap. 44 in more detail, a main area of research has dealt with field players' decision-making [1–3, 72, 73]. This brief section focuses on decision-making relevant perceptual-cognitive skills related to the recognition and recall of game situations.

In research on pattern recall, a common test design includes the presentation of (evolving) game patterns, followed by a mask and then a screen of, for example, an empty handball field where participants are asked to recall the position of all players previously shown towards the end of the (evolving) game pattern (for an illustration see Fig. 41.4). Since the classical study by de Groot [74] in chess, it has been shown that in several sports, experts remember structured patterns more accurately than novices. This difference diminishes in unstructured situations [75–77]. In handball, an early study by Tenenbaum and colleagues [78] demonstrated that especially in more complex situations, experienced players showed better performances than less-experienced ones. In a not yet published study by Schorer and colleagues, differences between experts and novices at the adult level as well as in youth players could be revealed. Experts outperformed their less-skilled counterparts in their recall performance. These findings were extended by Schapschröer and colleagues who studied the effect of physical load on pattern recall perfor-

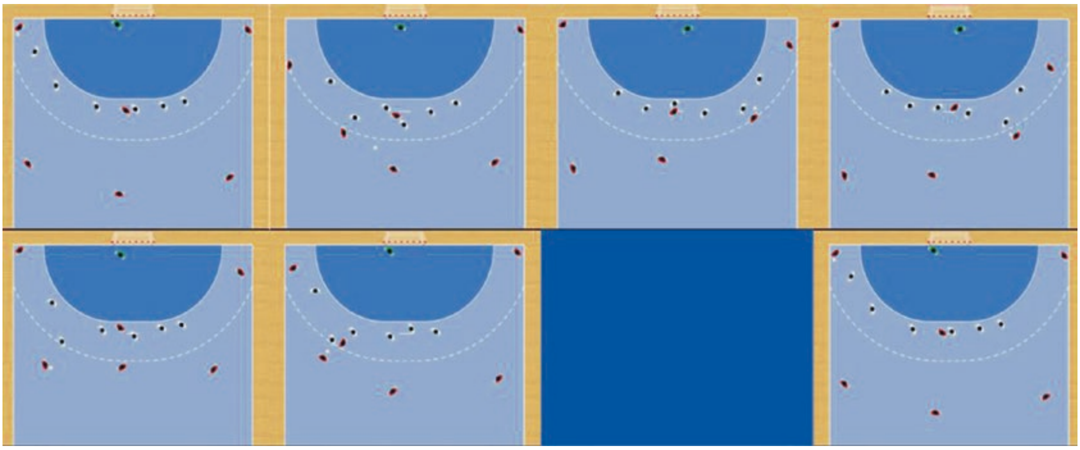

Fig. 41.4 An example of a pattern recall test in handball. In the top row, a pattern of play evolves, which is stopped at the second picture of the lower row. Then a masked screen is presented, in this case in blue, and the participants are asked to use the last screen (far right of the bottom row) to position the players as they were at the last frozen frame

mance in handball players [79]. While experts outperformed novices in the pattern recall task, there was no interaction between this skill and the varying physical loads imposed on participants. In another study by Schapschröer and colleagues, a change detection task was used to measure the tactical skill of differently skilled field players and its interaction with physical load and structure [80]. Experts outperformed advanced and novice players. Additionally, an interaction between structure and skill suggested that both skilled groups performed better in structured scenes, while novices were slightly better in unstructured ones. Again, the physical load had no impact on performance. Taken together, these findings show that pattern recall and recognition are clear characteristics of perceptual expertise in handball field players.

41.5 Perceptual Skills of Coaches and Referees

Unlike research considering the perceptual behaviour of athletes, research focusing on coaches and referees is relatively rare. Research on *coaches*, for example, examined visual search strategies across different levels of expertise in tennis [81–83], basketball [84] or swimming [85]. Generally, perceptual skills of handball coaches have been considered very rarely [8, 9].

In one study, Hagemann and colleagues investigated whether differently skilled handball team coaches used domain-unspecific strategies in a general problem-solving task [9]. Thirty-eight top-league coaches and 43 local-league coaches were compared. Results showed better problem-solving strategies of the top-league coaches. In a second step, the authors analysed the real-life coaching behaviour, showing that the top coaches used more concrete instructions and less utterances during competition. Another study examined perceptual-cognitive skills in differently aged and skilled handball coaches [8]. Specifically, Fischer and colleagues asked participants to perform a time-focused flicker test and an accuracy-focused pattern recall test. In the pattern recall test, licenced coaches were more accurate than novices and younger participants were more accurate that older ones. In the flicker test, the same pattern was found, with licenced coaches performing faster than novices and younger coaches performing faster than older coaches. To the best of our knowledge, besides the two mentioned, there are no other studies on perceptual-cognitive expertise in handball coaches to date.

Research on *referees* mostly focused on decision-making in sports like baseball [86, 87], soccer [88, 89] or ice-hockey [90]. For example, assistant soccer referees' gaze behaviour during simulated [88] or real [91] offside decision-making or baseball umpires' gaze strategies, while calling a pitch was compared between different levels of expertise [86, 87]. While handball referees have been the subject of research on various topics such as self-efficacy [92] or judgmental heuristics [93], research on perceptual skill in handball referees is almost absent.

The only study we are aware of dates back more than 20 years ago. Jendrusch, Schmidt, Wilke and de Marées [11] investigated differently skilled handball referees' ability to correctly identify whether a jump shot performed by a player approaching from the left wing position was performed according to the rules of handball (i.e. the ball left the throwing hand before the player made contact with the ground in the goal area) or not. In addition, the authors recorded the participants' static and dynamic visual acuity. Comparisons between 20 expert referees ('Bundesliga') and 20 less-skilled referees ('Landesliga' or lower) did neither reveal statistically significant differences in both acuity measures nor in decision-making accuracy. With regard to the latter, however, there was a descriptive trend of more correct decisions in expert than less-skilled referees, suggesting a potential expertise effect.

Taken together, in view of the demands in handball, coaches and referees are likely required to develop specific perceptual-cognitive skills to show optimal performance. However, only less than a handful of studies actually considered these target groups in handball. To solve this obvious contradiction, we urge on intensifying efforts aimed at both understanding and developing perceptual-cognitive expertise in (talented) coaches and referees.

41.6 Practical Applications in Handball Sports Medicine

At least two practical applications of this chapter's topic may be suggested for the field of handball sports medicine: First, superior perceptual skills might promote injury prevention. A player who accurately identifies where opposing players are and who 'knows' how and where they will be likely to move next (i.e. identification and recognition of tactical patterns) might better anticipate a potential foul against him or her. This, in turn, could help initiate appropriate and safe landing, for example. Similarly, goalkeepers might benefit from good anticipation of ball flight. If a handball is thrown towards the head of a goalkeeper and he or she is not prepared for it, then concussion could be one consequence (cf. current discussion in American football). Thus, the ability to read cues from unfolding events (e.g. a player's kinematics) and also being aware of the situation might be keys to injury prevention.

A second application is the use of virtual training of perceptual skills during the rehabilitation phase. This would allow, for example, referees to train their decision skills even when they are not able to perform on the field. Likewise, goalkeepers might train their anticipatory skills by means of a temporal and/or spatial occlusion task. Players could retain their tactical skills through the application of tasks like pattern recall or decision-making. While the effectiveness of these applications seems plausible to assume, systematic examination with regard to their measureable benefit for on-field performance is still pending.

41.7 Take-Home Message

Perception plays an important role in handball and is a characteristic of expertise in goalkeepers, field players and likely also in coaches and referees. Considerable effort has been invested especially in examining and understanding goalkeepers' and, to some extent, also field players' perceptual-cognitive skills. However, little is known about these skills in coaches and referees. Apart from its relevance to performance and high achievement, perception is potentially relevant also from a sports medicine point of view in that it might support injury prevention. For example, enhanced perceptual skill could help athletes orient better on the field, foster situation awareness and thereby facilitate avoidance of impacts by opponents or the ball. To the best of our knowledge, this hypothesis has not been tested in handball yet. The relationship between perception and injury prevention is one topic in concussion research, for example, in ice-hockey [94, 95], that researchers interested in handball might also want to look into in future work.

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42

Doping in Handball

Kai Fehske and Christoph Lukas

42.1 Introduction

So far doping has not been a major issue in handball. Endurance sports such as cross-country skiing, cycling, or athletics have been influenced tremendously by doping and the artificial improvement of physical performance. Since the introduction of modern handball as an Olympic sport at the 1972 Olympic Games in Munich, handball players are tested regularly for doping.

The first known handball player who was tested positively was Adrian Simion the goalkeeper of the Rumanian National team. At the 1986 IHF World Championship, his urine sample showed traces of ephedrine, and he was suspended by the IHF for 2 years.

During the last World Championship 2017 in France, 98 anti-doping tests were performed. Most of them have been performed after the games and only one third out of competition. The anti-doping tests were mostly urine samples, and under 10% were blood samples. Just one of the tests turned out positive.

The anti-doping database registered 114 doping cases in handball until 2017. Most of the cases involved substances classified as cannabinoids [1].

The WADA (World Anti-Doping Agency) statistics show comparable results. In 2012, 3964 samples were obtained in handball (2194 in-competition, 1720 out-of-competition tests). Almost 99% have been urine test and only 1% out-of-competition blood tests. About 1% of the tests showed adverse or atypical analytical findings, mostly related to the abuse of cannabis [2].

Positive testing for performance enhancement substances is rare which leads to the concept that the prevalence of doping in handball is very low. Suspicious activity of certain teams before and during competitions as well as positive cases involving steroids (anabolic agents) and amphetamines suggest placing handball under continues anti-doping surveillance.

42.2 Effects of Doping in Handball

As in other ball sports, handball is a very complex entity with several types of movement categories. On the field, the player has moderate to high demands on intermittent endurance running capacity [3]. Even though the physical demands differ between positions [4], the sport itself is highly demanding on the players' con-

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stitution. With up to 90 games per season at the elite professional level (i.e., players participating in the EHF champions league as well as being a member of the national team), the performance-enhancing effects of amphetamines and anabolic substances could be tempting. Complex skills such as the ability to throw a ball with high velocity into the desired target (goal), to react quickly to different game settings, or just to be a good team player are difficult to manipulate with doping. Teams that have taller players with higher fat-free mass tend to be more successful. Physical recovery as well as increase of fat-free muscle mass can be achieved with the use of anabolic substances such as steroid hormones, growth hormones, etc. Amphetamine-like substances could be used to raise the alertness of the player and improve performance by helping the player assess match play situations and overcome fatigue [2].

42.3 Testing the Handball Player

Professional handball players are tested irregularly. The current anti-doping regulations of the International Handball Federation (IHF) are implemented and supervised by the IHF Anti-Doping Unit. They fulfill the WADA code. The players are part of two different test pools: members of a national team and players of the national leagues/European leagues. National team players are within the Registered Test Pool. Those athletes have to reveal where they will be reachable between 6 in the morning and 11 at night for the upcoming 3 months. The so-called “whereabout” program is criticized by the players because it highly interacts with their privacy. If a player is not available for testing at the previewed location, it is a doping offense. Three missed tests are classified as a positive test result, and the player is withdrawn from practice and competition, which has happened in the past to national team players. The Adams app (https://adams.wada-ama.org/adams/login.do?nopopup=true), where players can indicate their whereabouts, should make it more convenient for the test pool athletes to inform the NADA (national anti-doping agency) about the changes in their schedule.

There are no specific regulations for competitions on how many players per team have to be tested and also on when to take the urine or blood samples. The IHF regulations are quite broad.

Anabolic substances aimed at increasing power and muscle mass and improving recovery will most likely be used in preparation for major events since they can be detected for a prolonged time in urine samples, and therefore, the risk of being tested positive in an in-competition test is much higher. Substances as growth hormones have a shorter detection window and are found easier in blood testing. Anti-doping experts suggest to implement a testing scheme with targeted urine tests approximately 2–4 weeks before the start of major competitions. To cover modern doping substances which are difficult to detect, additional blood samples are also being recommended [2].

42.4 The Athlete Biological Passport

The athlete biological passport is a system implemented by WADA directed toward enhancing the identification of those athletes accountable for the misuse of performance-enhancing substances [5]. Doping leaves a biological fingerprint in the athlete’s body. The athlete biological passport is the paradigm testing that aims to detect this biological fingerprint. Biomarkers of doping measured or inferred from blood and urine samples are used for that purpose in the same way that biomarkers of disease are used in medicine as indicators of the presence or severity of a disease [6]. The blood passport aims to detect any modification of erythropoiesis, whether by blood transfusion or the use of erythropoiesis-stimulating agents, such as recombinant erythropoietin [7]. The doping substance itself is not detected but rather its effects on the organism. After exclusion of any possible pathology, specific variation from the individual norms will be considered as a potential misuse of hormones or other modulators to enhance performance [8].

Recently, a new development of the athlete biological passport has been introduced which is aimed at detecting the abuse of anabolic hormones which could also be used in handball [2].

Until now, the Hungarian and the French handball federations implemented the athlete biological passport and carried out over 300 tests related to it.

42.5 Misuse of Non-Doping-Listed Medication

Another big issue is the widespread use of non-listed (not forbidden) general medication. It is known that many professional athletes including handball players suffer from chronic or subacute overuse reactions of their extremities (shoulder, knee, etc.) and therefore use painkillers such as nonsteroidal anti-inflammatory drugs (NSAIDs) during competition. This is not a direct performance enhancement through typical doping substances that improve alertness, body composition, endurance, and power, but those drugs can provide an indirect performance enhancement. Some players consume those substances in high doses which could lead to typical side effects including gastrointestinal bleeding and renal failure up to kidney impairment. There have been reported cases of severe organ damage, in one case even resulting in kidney transplantation (http://www.spiegel.de/panorama/leute/ivan-klasnic-klage-gegen-werder-bremen-aerzte-vor-entscheidung-a-1139873.html).

42.6 Nutritional Supplements

Many athletes use nutritional supplements such as creatine, amino acids, or simply vitamins to support their muscle growth or to recover quicker even though the efficacy is not certain [9]. One of the leading anti-doping biochemists Hans Geyer from Cologne, Germany, states that several recent studies have shown evidence of some nutritional supplements containing prohibited anabolic androgenic steroids, so-called prohormones, which were not declared on the label [10]. Within the last 2 years, nine German athletes including one female handball national player have been tested positive for prohibited substances after the consumption of nutritional supplements, and this has been a growing phenomenon in other countries as well. Findings in blood and urine samples have shown traces of the prohormone Higenamine, which has anabolic potential. The positive test led in all cases to a prolonged suspension from practice and competition. It is therefore necessary to educate players, coaches, and all handball personnel of these issues related to supplement use. When it comes to positive testing, lack of knowledge does not excuse the offense and is not considered an acceptable explanation by the enforcing bodies. Players and all handball personnel should be informed that only authorized and officially tested supplements should be used.

42.7 Doping Prevention

The main aspect of prevention in doping is awareness and knowledge. The athlete needs to be aware of prohibited substances. In most European sports leagues, it is mandatory to educate the players. Prevention and education should start already at a young age. Usually, at an early career stage, doping is not a real option. This may change as the athlete becomes a handball professional and his/her career, quality of life, and family income highly depend on being successful in handball. Since most positive tests have been from cannabinoids, especially the young player has to be aware that lifestyle drugs are also prohibited.

Similar to nutritional supplements, many other products or medications can lead to positive testing. For instance, consumption of overnight cold medications which is common and even the consumption of poppy seed cake could already lead to a positive result for opiates.

Education on doping issue should be a team effort. The personnel in charge of medical teams, whether at the national or team level, should be responsible and make efforts to provide such education or make sure it is provided. Consequences can often apply to medical personnel and may affect their careers as well as the players' careers.

Overall, it is important to note that players are not required to memorize every single substance on the prohibited list. They should be aware and have a responsibility to inquire about any drug/medication or substance offered to them and also be aware of the risks in consuming even "innocent" substances as nutritional supplements and certain foods.

The WADA Homepage (https://www.wada-ama.org/) contains further information on rules, regulations, education, and prevention.

Conclusion

Until now, doping is fortunately not a major issue in handball. The use of performance-enhancing substances does not seem to be common in the sport. Measures have been taken to maintain the cleanness of the sport. The main focus should be on prevention through education and raising awareness, especially in young players. Efforts should be made by the international and national federations to provide such sufficient education. Multilayer testing should be established in each federation based on the WADA code to detect doping offense and to protect the honest athlete.

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Part VI

Psychological Aspects in Handball

Check for updates

Psychiatric and Psychological Considerations in Handball Sports Medicine

43

Katy Seil-Moreels

43.1 Introduction: The Sports Physician's Role

The physician has a major impact on an injured athlete, especially in a professional or elite environment [1]. Although priority needs to be given to illnesses or physical injuries in most of the cases, these apparent diseases must not be considered as stand-alone or unique events. Ethical questions as well as physical and mental disorders are inherent to each decision-making process. The context of high-level athletes needs to be understood because the implications of their performance are manifold, reaching from societal to financial considerations not only for the athletes themselves but also for their team, club, or federation [2, 3]. In this respect, it is important to consider the physician's place in the sporting environment. Freedom in decision-making is not the same if the doctor acts as an independent expert or if he or she is employed by a club or a federation.

An injured player often puts his or her life and career into the physician's hands. Beyond the indication of a medical or surgical treatment, recommendations of a final or temporary arrest of the sports career may induce unexpected psychological consequences. Therefore, the human relation between the player and his or her physician is of utmost importance. The athlete needs to feel confidence, support, and security in these moments of vulnerability caused by physical injuries when critical decision-making may be required [1, 4].

In order to build this relation and eventually avoid underestimating the impact of psychological factors, the physician needs to understand the athlete's origin and environment. The athlete and his or her environment have been in constant evolution [5, 6]. Over the last century, the impact of sports has grown dramatically. From an economic point of view, it has become the second most important sector after industry. Although less developed in handball, financial implications are tremendous in many of today's elite sports. Sociologists claim that "the athlete" has become the ideal representative of the cult of performance, which is so typical of our modern society [7]. This "superhero" who is capable of always beating his or her own physical performance represents the perfect figure of an individual who is capable of always acting at the highest level of performance, of becoming a star out of anonymous social origins, only relying on his or her own strength and ability. Recent evolutions in football represent the best example of this perception. Depending on their status in the team, expectations from players are excessive, and injuries may have enormous implications. In case of physical injuries, an entire team will be made available to allow for an ideal rehabilitation and return to competition and performance in the

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shortest possible period. The games will go on; performance and results are required [8].

43.2 Psychological Injuries: The "Invisible" Injuries

The spectrum of mental, "invisible" injuries poses a challenge to healthcare professional in handball as well as in sports in general. Although it may be difficult for treating physicians to investigate them on a systematic basis, they should be kept aware of and considered in case of abnormal evolutions or recurrent injuries. A history of psychological trauma; psychological sequelae of a previous physical injury inducing fear of pain; anxiety of a recurrent injury, physical deficit, or handicap; the fear of loss of identity or social status induced by loss of athletic competencies; and the fear to lose simple personal landmarks in the activities of daily living induced by a lifestyle change, not to mention the risk of replacing physical activity and production of endorphins by the consumption of toxic substances, are all potential causes of psychological discomfort. Sports clinicians should also be particularly vigilant to detect clinical signs of psychopathological conditions like eating or addictive disorders or overtraining [9, 10].

The difficulties in considering these psychological injuries are related to the fact that the word "psy" is still inducing a taboo in our society in general and more particularly in the sports world. By definition, an athlete is an ideal model of balance and health, a physically and mentally strong and healthy human being to whom feelings like anxiety, vulnerability, and fear of competition or failure are "forbidden." But an athlete is not a superhero. It has been established that an intense sports practice is a factor of vulnerability, particularly in young athletes who represent a subgroup at risk to develop specific psychological disorders. Research in this field has significantly evolved over the last 20 years. This new knowledge allows to understand the complexity of sports psychology as well as the importance of a multidisciplinary approach to prevent sports injuries and related psychopathological disorders in athletes [11]. Such efforts of prevention should specifically become a priority in young athletes [1, 12].

There is no threshold from which an intensive sports practice can be considered deleterious, nor is there a psychopathological contraindication to high-level sports activity, with the exception of symptoms of anxiety and depression which may strongly predict the appearance of a burnout syndrome. Identifiable risk factors are personality disorders, negative influence by the family (e.g., inconsistent support; family pressure leading to overtraining or Münchhausen-type abuse), or the coach (pressure of performance, psychological or sexual abuse).

43.3 Psychological Aspects in the Young Handball Player

Young athletes in general and handball players in particular are not "small adults" and may be more susceptible to psychological insults as their character is shaped. The cumulated roles of the parent and coach(es) are of crucial importance and may influence and even inhibit an adolescent's normal evolution toward differentiation and autonomy [5, 13, 14]. The specificity of the adolescent athletes requires the recognition of their particular needs to allow for their healthy physical and mental development [15, 16]. Sports physicians/clinicians need to be educated according to the guidelines established by the International Olympic Committee in 2008 and 2015 [17–19]. In this document, a massive increase of complex medical interventions and surgical procedures was pointed out in young athletes. It was mentioned that an important amount of injuries was related to an excessive increase in training intensity, frequency, and volume. The risk of overtraining was considered to be similar to adults, with the exception that it is more difficult for adolescents to recognize their physical limits. These young athletes evolve in a sports environment which is dominated by the culture of risk taking and quest of performance in association with an ideology of pain as a necessary evil [20]. These youngsters are also more at risk to submit themselves to adults on whom they depend for their success.

43.4 Psychological Assessment Tools in Athletes

Specific tools have been designed for athletes (e.g., the French “Grille d’Entretien pour une Evaluation Multidimensionnelle du Sportif” [GEEMS], which may be translated by interview template for a multidimensional evaluation of the athlete, [21]) and may be helpful in athletic screening as well as for research purposes. Questionnaires like the GEEMS are based on a semi-directive interview, allowing to explore different items such as the players’ psychological well-being, eating behavior, physical integrity, family relations, and physical activity. These items allow to evaluate a majority of risk factors (Fig. 43.1) [22]. In addition to this, several psychological questionnaires have been developed specifically for return to sports issues after previous sports injuries (Table 43.1) [23–31]. Studies have shown the importance of stress factors in the occurrence of recurrent injuries [32].

43.5 Health Protection Strategies During and After a Player’s Career

The question how these ethical and medical considerations could be disseminated to the players’ environment should be addressed, especially for the youngest and most vulnerable among them [33]. The question of a player’s health, his or her physical and psychological well-being, as well as his or her future professional life, be it in sports or not, should be among the priorities of sports clubs and federations and be part of their specific health protection strategy. The impact of psychological

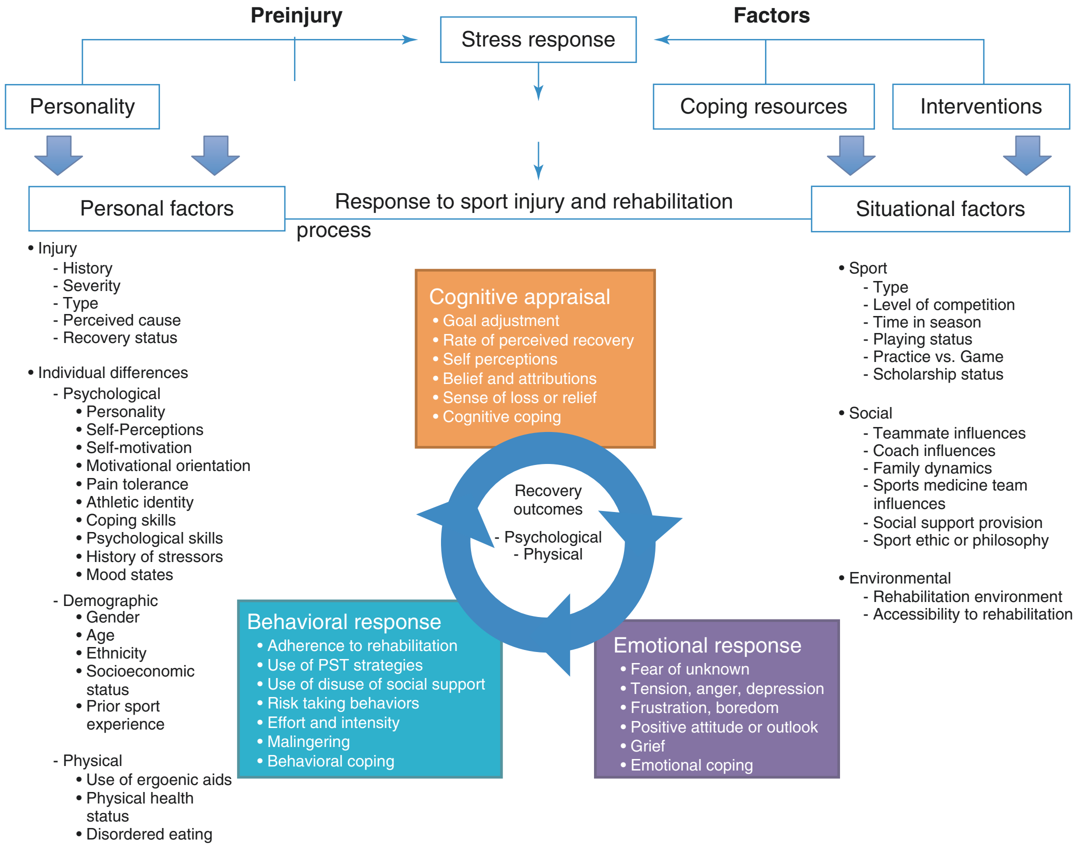

Fig. 43.1 Integrated model of psychological response to sport injury (adapted from [16])

Table 43.1 Self-report measures of psychological readiness to return to sport following injury (adapted from [20])

Measure	Assessed readiness characteristics
ACL Return to Sport after Injury (ACL-RSI) scale Webster et al. [31]	Fear, anxiety, confidence, risk appraisal
Attention Questionnaire of Rehabilitated Athletes Returning to Competition (AQ-RARC; Christakou et al. [25])	Functional attention and distraction when returning to sport competition following musculoskeletal injury
Causes of Re-Injury Worry Questionnaire (CR-IWQ; Christakou et al. [24])	Re-injury worries due to rehabilitation and opponent ability
Composite Return from Injury to Sport Scale (CRISS; Ankney et al. [23])	Confidence, achievement, support, rehabilitation experience
Injury-Psychological Readiness to Return to Sport (I-PRRS) scale Glazer [27]	Confidence
Need Satisfaction Scale (Gagné et al. [26]; adapted by Podlog et al. [34])	Satisfaction of basic psychological needs (required for self-determined motivation)
Re-Injury Anxiety Inventory (RIAI; Walker et al. [30])	Rehabilitation anxiety, return-to-competition anxiety
Sport Injury Trait Anxiety Scale (SITAS; Kleinert [28])	Concerns about injury
Tampa Scale of Kinesiophobia (TSK; Miller et al. [29])	Fear of movement

factors and the risk of mental decompensation in case of a sports injury, of overtraining, or of arrest of sports practice should not be taboo themes anymore. Experience has shown that the best programs of prevention will not work if the environment (e.g., coaches, parents, clubs, the athlete him- or herself) does not comply and adhere to them [1, 12]. Sports physicians and moreover sports psychiatrists are not systematically part of this environment. Information campaigns and interdisciplinary exchange become mandatory to help the sports world to consider the athlete's health and well-being as a number one priority. Testimonials of high-level athletes such as swimmer Penny Heyns may be a good option to shed light on the problem [35]. She published ten advices to young athletes and their parents, illustrating the importance of a personal development outside of the sports world, of having courage to ask for psychological support despite the fact that an athlete is not supposed to be depressive, of sharing his or her emotional problems in order to realize that they are normal, and of thinking on the time after sports activity before being confronted to it.

Another problematic phase in a player's career causing a significant psychological burden is the end of a career where the aging competitive player or perhaps even the recently retired athlete has to deal with their return to the "real world," often without sufficient tools. The EHF has recently established a program through Las Palmas University in Gran Canaria, to facilitate a pathway for former handball players to more easily gain an academically recognized degree (first through gaining structured coaching education) which would enable them to integrate better in the working environment and open various options for them [36]. This trend is slowly being recognized and addressed by other big sports associations like the FA premier league (football) in the UK, the NBA, and several national Olympic federations – supplying the athletes' additional tools to cope with "the day after."

43.6 Summary

In order to take care of sports injuries, sports physicians need to have a complete knowledge not only of physical diseases but also of the psychological and psychiatric disorders which may affect a player's health. The role of psychological factors in the occurrence of sports injuries is still underestimated or insufficiently known. These aspects need further consideration and investigation, both from a clinical and scientific perspective, in order to be successfully implemented for the prevention and follow-up of sports injuries. Among them, the social and family environment and the player's individual history are essential for a personalized approach of the player. Psychological assessment tools and educational pathways for clinicians and coaches are required to apprehend the players. On a superior level, strategies need to be developed in the sports world to protect the players' physical and psychological well-being.

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Decision-Making in Modern Handball

44

Peter Weigel

44.1 Characteristics of Typical Situations in Modern Handball Sport

Successful handball players have to be more than tall or well trained in skills (e.g., throwing powerfully and precisely). Especially at the high-performance level, there are more abilities which distinguish players. Specific rule modifications support this fact (e.g., fast throw-off, seventh field player). The modern handball sport is made of many situations, in which every team player has to decide for themselves in a very short period of time. In accordance with similar game sports (e.g., basketball, soccer, hockey), the ability to make correct decisions (or to perform the right motor answer) in complex game situations has shifted into the center of athletic performance.

Highlight-box 1:
At the highest level of perforance, the ability of decision-making is crucial for distinguishing between good and better handball players.

This decision-making process in typical handball situations, both offensive and defensive, depends on a high of typical influences of real-world setting. From the audience's point of view, a high and thus attractive tension arc is created at this point. From a coach's point of view, certain conditions and content must take place during the training process. Orasanu and Connolly [1] described eight conditions for real-world settings which are the basis for every decision: action/feedback loops, multiple players, ill-defined or competing goals, uncertain dynamic environments, time pressure, ill-structured problems, organizational goals and norms, and high stakes. The simultaneous presence of each of these properties leads to the complex context in sports games such as handball.

The generation of actions does not depend solely on the players' current situational perceptions, but also on the stored experiences of the decision-makers. In similar constellations, players tend to perform the same actions if they have been successful in the past (action/feedback loops). But in team sports, there are always persons involved other than the decision-maker. There are direct opponents with their goal to keep the ball away, and there are teammates with their own decisions (multiple players). The first goal of teammates is identical to the decision-maker (offensive, goal scoring; defensive, ball profit). But the ways in which this goal is reached can differ between teammates or can change

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over a short period of time (ill-defined or competing goals). Because of this, every player has to account for their own decision-making-process as well as the decision (and the motor action) of every teammate and of every opponent. These dynamic conditions can result in incomplete or missing information. The high time pressure prohibits the complete perception of the situation. The decision-maker has to select the main information for the following cognitive process, while other information will not be further processed (uncertain dynamic environments).

The decision-maker must choose between many possible options, which can even be contradictory (e.g., ill-structured problems such as throwing or passing to one teammate). Because of the fast game character, there is no time to compare the different options which could lead to success [2]. The player has to make those precarious decisions under a high time pressure as a result of the action by the opponents and the given rules of the team sport. This choice must be given in a very short time and under the influence of several opponents. Because of these special aspects, the stake for losing possession after a bad decision and/or a wrong action is relatively high. The success of the chosen option cannot be predicted, because the actual situation is constantly changing. In addition, the decision-maker must be able to predict the subsequent actions of teammates and opponents, without taking any direct influence on them (organizational goals and norms).

The specific conditions in a real-world setting kept off the process of decision-making as a description of comparison of different options. Furthermore, the actual constellation and subsequent cognitive processes take influence in decision-making [3]. In conclusion, improving the quality of decision-making means to improve cognitive processes of each decision-maker in connection with situational perception. This requires the analysis of the complete decision-making process. The consideration of the real-world settings [1] in lab-based studies on decision-making allows the transfer of the findings to the real world [4, 5].

Highlight-box 2:
To improve the quality of decision-making of the whole handball team, the coach has to improve cognitive processes of each decision-maker in connection with situational perception.

44.2 Decision-Making Under Realistic Conditions

In sports games like handball, there are specific conditions for decision-making. On one hand, it is still a game without life-threatening stakes (in contrast to other realistic decision-makers like fireman or military leaders). On the other hand, handball game seems to be an idealistic field of researching cognitive processes under real-world settings. For analyzing the process of decision-making, you will have to analyze the situation in which the decision-maker is located.

The approach of natural decision-making (NDM) takes into account the settings of the real world [6–8]. The aim of NDM is to understand how people make decisions under real-world settings. NDM consider the actual situation and their certain issues, which taken influence to people who actually make decisions in real situations. The setting by Orasanu, Connolly [1] are one of two roots. The other one is the criterion of “satisficing” [9]. Human decision-makers have cognitive limitations [10]. Satisficing means that people choose an option as soon as this will reach the goal—independent if this is the best option [11].

The NDM approach includes nine single models of decision-making [3]. Depending on the specific constellations and properties in the situation, the different models can explain the decision-making behavior. In following, the models will be shortly described and will be tested for compatibility to the field of handball (for more and detailed descriptions, see [12]).

The *cognitive control of decision-making* [13] situates the process on a continuum between knowledge based (deliberately) and skill based (intuitively) and depends on degree of consciousness. If the decision-maker is in an experienced situation, the cognitive effort will be set low. No conscious control is required (similar to motor reflexes). Unknown situations require a high degree of cognitive processing. Regarding high performance level players, it must be accepted, every situation is acquainted and the decision-making is the result of skill-based processes. From this circumstance, neither assignments for knowledge to skill-based processes can be derived (for the actual decision-making-situation) nor are there any training hints to improve the cognitive process. According to this model, experienced decision-makers in handball should always generate the right option. But in real, even the world handball players decide for the wrong option and make mistakes in the game. Also this model does not give any notes to false-generated options.

Another model, the theory of *decision cycles* [14], assumes the decision-maker creates cognitive images of the real world. The dynamic situations are explicitly taken into account. Every motor action leads to a new cognitive image, as long as there is no satisfying solution. Every handball player performs the best individual option until the success or until the game is over. On one hand, this model explains the decision-making process in theory. But there are no empirical approved findings. Because of this, there are also no hints for training decision-making.

The model by Lipshitz [15] describes natural *decision-making as argument-driven action*. These arguments refer to assessment of situation and weighing the consequences. Furthermore, there are no hints for recording or processing information. The model is comparing to decision trees and assumes low time pressure. Because of this, decision-making by handball players cannot be described with Lipshitz [15]. However, the model can well explain strategic decisions of the coach, like defensive formation or player changing.

As well, the model of *explanation-based decisions* [16] assumes less time pressure. It describes decision-making in a complex context of situation, advantages, disadvantages, and opinion of other involving people. Pennington and Hastie [16] explain decision-making in the field of jury court (judge and juror). This model is also not suitable for the decision-making behavior in fast-changing situations in handball.

The *image theory* [17] used also cognitive images. But in contrast to Connolly and Wagner [14], the authors describe different attitudes, values, and knowledge by images. The decision-making process consists of screening and choice phases. Stored images and the actual information will be compared in the screening process. Hopeless options are hidden. Suitable options will be checked for benefits with the aim to perform the best option. Decision-making in handball cannot be representing as such linear process. The ill-defined goals, uncertain dynamic environments, and their constantly changing in a short time are not taken into account in the image theory.

The *recognition-primed decision-making* (RPD) model [6, 18] describes the involved cognitive process with three steps. At first, (visual) information will be recorded until the situation can be successfully compared with the person's stored experiences (intuitive part of the model). Subsequently, one option will be generated. In the third step, this option will be checked for suitability to the actual situation (mental simulation, the analytic part). If it is positive, the motor action will be started (otherwise, another option will be generated). This corresponds to the "notion of satisficing" [9], which consists of an analytic and an intuitive part. However, the limitations of this model become apparent if the decision-maker assesses the situation as new and unknown. On the other hand, known situations lead to well-established and typical follow-up actions. The decision-making process in handball can therefore be explained partly on this basis. In addition, several findings exist to confirm this theory. Therefore, the RPD will be taken up again in the third section.

Highlight-box 3:
Decision-making in real includes an intuitive and an analytic part. And the cognitive process will be stopped, if the first option is reaching the individual goal by mental simulation.

On the basis of the model of *search for dominance structure* [19], the decision-maker compares in detail the advantages and disadvantages of every option. This requires searching and recording of detailed information. However, this model does not explain how information is perceived or compared. Furthermore, in typical handball decision-making situations, there is not enough time for searching, recording, and comparing detailed information.

The *situation assessment theory* [20] focuses the context of the organizational goals and norms. Actual information about the decision-making situation are neglected. The options generated depend on the experience, knowledge, and views of other possible decision-makers. While this model is suitable for describing phenomena which solve complex tasks such as computer software [20], it is insufficient for describing human decision-making.

The *task characteristics and human cognition* model [21] explicitly postulates the dynamic settings of situations, and it offers solutions for analytic and intuitive processes. But the model does not describe influential takeover by the decision-maker, only the ability to anticipate real situations. Lusk et al. [22] evaluated this model by anticipating the weather. For sports games, especially handball, it is not suitable.

To explain decision-making in the field of the sports game handball, there are two other closely related possibilities: decision cycles and recognition-primed decision-making. The other models discussed above include elementary limitations. The disadvantage of the theory of decision cycles is that there are currently no empirical findings to support its assumptions. The RPD is, on the other hand, supported by scientific findings. Klein [6] describes the process of decision-making as a recognition process of matching a specific situation with experiences within domain-specific knowledge.

The RPD was formed on the basis of interviews with fireground commanders [2, 18], intensive care unit staff in hospital [23], military officers [18, 24], and navy officers [25]. The authors evaluated the decision-making processes of individuals and groups which must make decisions under high time pressure and with high risks. The interviews of fireground commanders directly after an emergency call clarified that the persons did not choose between two or more options. The commanders specified they acted because of their own experiences and not like an if-then rule or a decision tree [18]. Calderwood et al. [26] and Klein et al. [27] first evaluated the RPD in (chess)sport. In this game, players with different tournament ratings must solve specific constellations intuitively (highly time pressure: 6 s/move) and without time pressure. The more successful players made better moves than the less successful players under high time pressure [27]. Without the time pressure, the quality of the moves of both studying groups was equal. Johnson, Raab [28] confirmed this result in the field of handball. Young players (age of 14–17 years) were asked to watch different videos of offensive handball scenes. Upon the external stopping of the videos, the handball players had 5 s to call their intuitive and deliberate options for ongoing play. The more successful players (the higher performance class) intuitively generated better options and reported fewer options than the players of the lower performance class. As a consequence, the authors concluded that highly experienced decision-makers should choose their first generated option for motor action (take-the-first-heuristic; [28]).

The RPD seems more suited for describing the advantages of experts than novices in real-world settings. Decision-makers with the more successful option refer to different aspects than those with the less successful options. Experts also generate fewer options than novices [26, 28]. This reflects a better underlying ability to classify the current situation more precisely [29, 30]. In real situation, the more successful decision-makers choose an option whenever it reaches the goal. And this is independent of whether or not there are more successful (better) alternatives (notion-of-satisficing: [9]). By this account, experts can decide and act more quickly than novices [3, 27, 28].

44.3 Decision-Making and Its Application to Modern Handball Sport

The approach of natural decision-making deals with specific contexts. In doing so, real aspects are of central importance. More precisely, the context, the evaluation, the dynamic process, the use of mental imagination, and the number of motor options are central aspects of this approach. Sports games such as handball are characterized by special settings. The actions, expectancies, and plausible goals are virtually predetermined by the rules of the game. For these reasons, RPD will be further specified.

The high time pressure and the central role of intuitive and deliberate decision-making can be described particularly well with DEMATS (decision-making in team sports; [31, 32]). The model can be understood as a continuation and adaptation of the recognition-primed decision-making model to the field of handball sports game. The theory and findings of RPD will therefore be further elaborated. DEMATS is specifically formulated for the special situations in the game of handball.

Highlight-box 4:
DEMATS is an enhancement of the RPD model, especially for typical team sports like handball.

The decision-making model describes the cognitive processes in typical situations under high time pressure in sports games. Furthermore, the model also considers all of the conditions occurring in real situations [1] and the transition from cognitive to motor action. The notion of satisficing [9] is also taken into account. This model describes the decision-making process in quick and complex situations occurring in team sports games and offers alternatives if the option does not successfully achieve the goal ([32]; Fig. 44.1).

In a typical decision-making situation, the person first searches for (visual) information

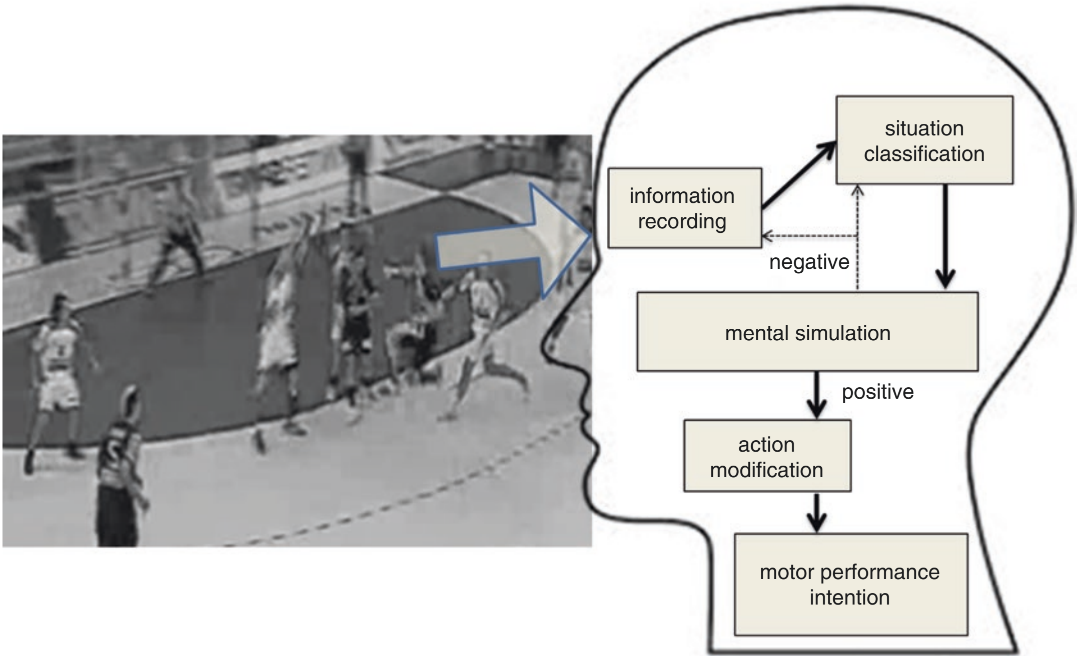

Fig. 44.1 Modell of decision-making in team sports [32]

(e.g., position actions of other players). This information will be compared will or similarly recognized experiences (situation classification; [6]). At this point, one single action will be generated and go through the process of mental simulation (similar to take-the-first-heuristic; [28]). This stored action of the past situation will be compared to the current situation. If this first action reaches the goal, the decision-maker will implement this with a motor answer (positive mental simulation; satisficing criterion). Otherwise, the action will be modified, or another possible action will be recognized and checked again with mental simulation (negative mental simulation; [6]). The alternative selection is made serially with respect to the typical properties of the individual options (recognition-primed process). The decision-makers have to think about one single action, and if it works, other possible actions are irrelevant. This is why the motor answer can be started in a very short period of time without comparing different actions.

Highlight-box 5:
Decision-making as a cognitive process occurs before motor action.

This model of decision-making describes the cognitive aspects of intuition (situation classification) and analysis (mental simulation). The classification part of the model is used to structure the situation and generate the action. The situation classification corresponds to the main aspect of this model. Klein [6] divides classification into four aspects (plausible goals, relevant cues, expectancies, and possible actions). In team sports (and especially handball), the set of rules limit the range of these aspects. In the mental simulation part, the generated option will be checked for feasibility and goal reaching [27, 32]. Furthermore, the mental simulation can indicate difficulties of the generate option and the possible outcome in the actual constellation. Domain-specific expertise leads to early, differentiated mental simulation.

The motor decision will not be started only because of recognition. Rather, the experienced option is tested for feasibility in the actual situation. On the other hand, the general parts of decision-making will be considered (perception, decision-making, motor action). DEMATS explains the influence of visual information and recognized experiences in the special field of handball.

DEMATS has been tested in the field of handball (overview: [32]). The studies considered real-world settings in an experimental small world [4, 5]. Therefore, typical decision-making situations are constructed on the base of real-world settings (study 1 presented the scenes on a screen showing a tactical board; study 2 presented real scene on a video wall). Handball players with different level of performance watched these decision-making situations with the aim to reach the goal. They had to act for one player. After stopping the video (point of time, when the player wants to throw on goal, given the final pass, or do another individual action in this scene), the screen became black and no other information are given. After calling the individual action, the next scene was started (for more see [31]). The studies are given the same findings. Handball players with the higher level of performance are generating the more successful action, and they are searching for information by watching the opponent players (active gaze behavior; results by analyzing the gaze behavior while watching the scenes). The players with lower level of performance watch their teammates and give their motor answers as actions (passive gaze behaviors; [32]). These findings offer important implications for training the single cognitive processes of decision-making.

Highlight-box 6:
Handball players with different performance levels generate different options and use different gaze behaviors.

44.4 Consequences for Teaching and Training in Modern Handball Sport

The model of DEMATS is not designed for anticipating the results of decision-making processes. The benefit is in describing the cognitive process of decision-making in a real-world setting. Furthermore, the model (and the different findings for RPD and DEMATS) offers several suggestions for improving this cognitive process to achieve greater success in handball. In accordance with Klein [33], domain-specific decision-making in handball cannot be improved in isolation. A basic requirement is that expertise must be build up. The main goal in decision-making training is to create more situations for deciding [32, 34]. It is accepted that in order to learn decision-making, the players must make decisions. Consequently, there are also some practical methods given for creating single games or exercises during the training process. These aim to improve various aspects of this complex cognitive process.

The decision-maker has to learn to act as a result of the current constellation and not as a result of saved actions (typical team moves). Even if the following statements refer to offensive constellations, they also can be used for defensive action. Furthermore, the suggestions should be seen as a meaningful addition and not as a substitute for specific parts of comprehensive handball training. Of course, handball players must learn many different actions and moves to be successful. For training decision-making, the players need to also improve the cognitive process of information searching and recording. These are the starting points for decision-making and should be a basic part of training. The resulting suggestions refer to the different aspects of DEMATS and will be explained by typical methods in handball training (Table 44.1).

Highlight-box 7:
Specific conditions in practical training lead to the improvement of decision-making.

Table 44.1 Resulting hints for practical training of decision-making

Process of DEMATS	Practical consequences
Information recording	• Games and exercises in majority
Situation classification	• Typical basic ball games • Create a multitude of decision-making situations (open-ended situations) • Instruct differentiated opponent behavior
Mental simulation	• Analyze decision-making situations on video • Use software for creating situations • Individual decision-making should be promoted and encouraged

Games and exercises in majority aim to actively intervene in information recording. Because of the few number of opponents, the decision-maker can process less information at the same time (especially for novices). The (visual) information should therefore be increased over time (e.g., more teammates and opponents). Therefore, the coach can use many different variants of simple ball game, specific majority handball constellations, or a passive teammate (only to passing). If there are more teammates than opponents on the court, the ball carrier always has a free-lance teammate. The need to search for his/her teammate is eliminated so that the player can concentrate on actions of the opponents. The attention will then change from teammate to opponent movements. This gaze behavior is typically for more successful decision-makers [32].

Basic ball games use simplified rules and goals of the sports games. The complexity of these games can be increased by adjusting the rules to the level of performance. Furthermore, the simplified decision-making situations are very similar to those found in handball. If these constellations are used again and again in training, the players will learn and store them in a variety of ways. Having many different stored constellations will facilitate classification in future decision-making situations [34]. This is reflected in quicker and more accurate recording and applies to many different motor answers in similar constellations. The decision-maker is thereby more able to generate at least one motor answer with a greater probability of success. Throughout the training course, quantity should be prioritized more than quality.

Different constellations are also constructed during training by using other opponents. Every player has typical defense movements and action, which results in different constellations in the game or exercises. In addition, when there are different opponents in the defense, the offensive players (decision-makers) have to react to these variable settings. In contrast, the same players (same opponents) are always involved in the training. The coach can instruct these players in different ways or in different behaviors and actions. There are therefore always constellations which differ from each other. As a result, the decision-maker has to search specific information to correctly categorize correctly the current situation.

To train decision-making, the coach has to continuously create open-ended constellations on the court. The players should be encouraged to solve these problems individually, rather than as a result of stored team movements. Team movements are a sequence of stored actions by the teammates, mostly independent from the opponent actions. The findings of DEMATS [32] describe the higher probability of success if the action results in opponent movements. Open-ended constellations or movements lead to differentiated stored experiences depending on the variable situation settings. The coach can use typical methods like deliberate play [35] or deliberate practice [36] to create many different open-ended constellations.

Decision-making training does not necessarily have to be executing practically. Former games can be used for showing typical decision-making constellations on a screen or a video wall. The players can name their own options for moving forward in the situation and they can discuss them, with particular attention to regarding to probability of success. Furthermore, the most important visual information can be clarified. Using the team's own games and the games of different teams provides access to a nearly endless number of decision-making situations. The scenes can be shown in real time and in slow motion, or they can be stopped at a specific time point. As a result, improvements in mental simulation can be achieved. The coach can name and justify important information. Analyzing video is equally important for experts and for novices alike. Subsequently, the actions generated from these discussions should be implemented in practical training.

Modern techniques enable the coach to create such decision-making constellations on a computer or tablet. The scenes can be shown simplified with only the necessary information. This technique is an especially useful tool for novices to gain exposure to a number of decision-making situations. There are currently specific software and apps for creating these scenes. Similar to video analyzing, the decision-maker must search and categorize different information, generate a possible action, and check the results with mental simulation. The coach can either intervene in these processes or not. Furthermore, the coach can identify causes of faulty options by the players.

Independent to each given suggestion, the coach should promote and encourage the individual decision-making of every handball player on the team. To be successful in the game of handball, it is not sufficient to simply train the entire team in movements. Players must decide quickly and correctly, especially in unpredictable situations. The foundation for these abilities is the training of the individual decision-making processes of each teammate. The performance of the team is the result of the performance of every member of the team. The coach should therefore also create spaces for wrong generated options, especially with novice and youth players. This will also be stored as an experience, and in equivalent situations, this player will be less likely to generate again this bad option. Not successful actions will also be helping the decision-maker to solve future situations in a more successful way. This should be the ultimate aim of training decision-making.

Highlight-box 8:
The coach is able to improve the quality of decision-making processes of a handball team.

44.5 Conclusion and Perspectives

Decision-making in handball is more complex than simply judging the right or wrong generated option. Rather, the actual conditions must be considered as well as the domain-specific experiences of every single participating player. Their influence on the decision-making-process is more important than previously understood. Successful actions are the result of decision-making under high time pressure, the involvement of teammates and opponents, as well as the given rules of the game.

These specific real-world conditions include, among others, the influence and dependence of other persons and the resulting uncertain dynamic environments [1]. Furthermore, ill-structured problems and competing goals are typical for these situations. The approach of natural decision-making provides useful models for describing such processes in the real world. Each model refers to specific conditions, benefits, and limitations (e.g., the extent of time pressure, the possibility of influence on situation continuation).

Decision-making in sports games such as handball is particularly well understood within the recognition-primed decision model [6]. This model considers individual experiences, current information, and intuitive and analytic processes. The typically high time pressure involved for decision-making in such situations is taken into account. RPD does not assume that different possible actions will be compared for a best option before beginning motor action. Instead, the first generated option for reaching the goal in mental simulation will be performed. This corresponds to notion of satisficing [9]. It is not a prerequisite that this option is also the best answer in the situation. However, the model also has its limitations. In handball, there are given rules which determine the plausible goals, possible actions, and the visual cues (parts of recognition process in RPD).

Therefore, the model is particularly well-suited for handball and similar sports games. Decision-making in team sports (DEMATS) corresponds to the specific describing of decision-making on the basis of RPD. Because of the limitations imposed by the rules of the sports game, the recognition process can be considered as simplified. Recorded information in the decision-making situation will be compared with stored experiences (situation classification). Subsequently, the typical motor answer will be generated and verified in the actual situation (mental simulation). If this cognitive process is successful in reaching the goal, this option will be performed. The negative mental simulation either leads to changing of the option or recording further information. DEMATS uses experiences, (visual) information, superior strategic requirements, the given rules, and differentiated cognitive process under high time pressure (intuitive and analytic). The model describes goal-reaching options as well as incorrect processes in decision-making, in the event that the generated option will be unsuccessfully performed.

The scientific findings of DEMATS build upon those of RPD [2, 23, 26]. Furthermore, there are scientific studies supporting DEMATS (for summary in [32]). All those findings confirm the more successful options generated by experienced decision-makers (experts). Also, the experts search for information by regarding the opponent's players (active gaze behavior). Novices spend more time watching their teammates and reacting to their actions (passive gaze behavior). However, it must be clarified that DEMATS has no possibility for prediction. Rather, it is a model for describing and analyzing of already made decisions.

The basic assumption of this model is that successful decision-making requires stored experiences. This is important for coaches. The acquisition of decision-making ability is a long working process which should ideally begin in the early years of handball playing and continuously develop. Furthermore, focusing on all experiences (even bad decisions) in the early years, and not just the good decisions, is important. With bad decisions, players can learn difficult constellations and goal-missing actions. This is useful for good decisions in the future. The following principle can be formulated: the quantity of decision-making is much more important than the quality of any single decision (especially in the early years). The high number of experiences enables the handball player to more often generate the right option in the future. This leads to the question of what the coach can do to give as many experiences as possible to his/her team. Certainly, every person has to make their own experiences. But the coach can support which experiences team members make while giving methodological suggestions. The formulated suggestions above should be useful for training decision-making. They can therefore be used in different games or exercises during training time. Decision-making can be trained in real situations and also constellations shown on a screen. However, the conditions should be as realistic as possible. Even though there is currently no scientific support for these suggestions and their effects on improving cognitive processes, DEMATS offers appropriate and logical solutions.

Highlight-box 9:
There are no wrong generated options in team sport situations. But there are faulty cognitive processes.

However, these processes can be trained and improved.

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45

Psychological aspects in Handball Injuries

Johanna Weber and Manfred Wegner

45.1 Psychological Factors in Team Handball in Different Settings

45.1.1 Psychological Demands in Team Handball According to Literature

This chapter aims to discuss the current status of research regarding these matters. Psychological performance-limiting factors in general and per position with an additional emphasis on female players are described as well as the association between psychological factors and injuries in team handball with a special focus on psychological predisposition to injury and return to sports.

Sports psychology in team sports commonly deals with events prior, during and following sports activities [1, 2]. Personal psychological factors influence the competitive ability [1] as well as team-related aspects like cohesion, which in itself is linked to personality traits [3]. Psychological aspects are frequently regarded as performance-limiting factor in team sports, such as netball [4] and soccer [5].

For handball, current literature also names performance-limiting psychological factors (e.g. mental toughness), although only few studies have been undertaken so far. Mental toughness has to be seen as a multidimensional construct consisting of self-efficacy, motivation, action-control (action-oriented), tolerance for frustration, intensity and stress, mental endurance, self-regulation, commitment, concentration and probably other factors [6]. It is likely that players have to be able to perform well under pressure, recover quickly from mistakes and tolerate frustration and pain while having the qualities of a fighter [7], so it is to be expected that mental toughness is performance-relevant in team handball. Its foundations are not yet clearly specified, although some of the mentioned factors seem to be linked to action-control, motivation and volition.

In other team sports like soccer, volition is seen as a crucial factor for performance [8]. Krause, Kärcher, Munz and Brack [9] also mention volition as performance-relevant in soccer next to motivation and the ability to act fast and correct. Seidel [10] found handball players to be more action-oriented than swimmers and track and field athletes, while Brack [11] expects differences between positions in action-control (half backs being action-oriented shooters, i.e. players who rather shoot at the goal than think, centre backs being state-oriented playmakers who plan the game). Gonçalves, Rama and Figueiredo [12] claim psychological factors to be useful as a predictor of talent, while at the same time Moesch, Hauge, Wikman and Elbe [13] found volition to be a predictor for the development of talent.

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Lidor, Falk, Arnon, Cohen and Segal [14] showed that physical tests were no selection-criterion for the national youth team of Israel. Since slalom dribbling was crucial for selection, the authors surmise that cognitive skills might be relevant. Silva [15] names several psychological factors to be important in team handball from his experience as an international coach: motivation, will, ability to recover quickly after an error, anticipation, ability to deal with visibility on-court, court-sense, mental toughness, discipline and flexibility, dealing with anxiety, pain tolerance, self-confidence, mental endurance, ability to work for the team, optimism before matches and dealing with emotions. It has to be mentioned that although the performance-relevance of psychological skills is familiar to coaches and there are studies concerning the improvement of performance after psychological intervention [16], a study by Reverter-Masía et al. [17] showed that from 14 tested handball clubs, not a single club had a full-time sports psychologist, while in soccer, 40% of the clubs were employing one.

The following psychological factors have already been researched in team handball players (Tables 45.1 and 45.2):

There are contradictory results regarding task- and ego-orientation [22, 23, 27, 43]. Li and Chi [18] found that perceived competence as well as precompetitive anxiety is likely to confound the effects of task- and ego-orientation. Players with high perceived competence will more likely interpret competitive anxiety in a way facilitative to game performance, no matter whether their task- and/or ego-orientation is high or low. Task-/ego-orientation might therefore not be performance-relevant to team handball if not occurring together with a high perceived competence. In consequence, next to the highlighted factors in Table 45.1, perceived competence can be considered beneficial for handball performance.

Most of the aforementioned studies refer to male players and do not distinguish between positions. However, there have been studies researching positional demands.

Table 45.1 Findings regarding psychological aspects in handball (m = male, f = female)

Findings regarding psychological aspects	Study
Task- and ego-orientation as well as direction of precompetitive anxiety are linked to perceived competence of a player	[18] m Chinese students
Attention not related to expertise level	[19]
Playing experience correlates with aggression in male and female Greek players while men have higher values than women	[20]
Connection between anger, vigour and training load in male competitive players	[21]
Elite and nonelite players do not differ in task- and ego-orientation	[22, 23]
Good results in Men's Asian games despite insufficient physical preparation, at the same time good results in the OMSAT-3 questionnaire which tests for mental skills like foundation, psychosomatic and cognitive skills	[24] Iran m national team
No difference of assertive level between male and female players; handball players are more extroverted than overall population	[25]
Selected youth players had nonsignificantly better values in unspecified psychological questionnaires	[26]
High task-/ego-orientation (task slightly higher). Experienced players/players playing longer for a club were more ego-oriented	[27] m
High values for impulsivity, anxiety, aggression, sociability; low values for activity. Psychological intervention improved these values	[28] m youth elite
No success-related differences in mental energy, athletic engagement and optimism, only age-related differences	[29] m youth

Table 45.2 Performance-relevant psychological aspects in handball (m = male, f = female)

Psychological factors related to performance/expertise	Study
Concentration	[30] m, [31] f
Perception	[32]
Anticipation, motivation	[31] f, [33, 34]
Ability to observe	[31] f, [35]
Decision-making	[31] f, [36] f
Situative determination, reaction, psychomotoric coordinative ability, operational readiness, stress tolerance and self-confidence	[31] f
Improved attacking performance after training psychic energy, direction of stress, aims, attention, concentration, mental imagery	[37] m youth
Personality traits in youth players	[10]
Handedness	[38–40]
Low results for dissimulation in elite players	[41]
Intuition is related to expertise	[42]
Ability to vary actions	[43] m
Ego-orientation	[43]
Volition (self-determination, not postponing training)	[13]
Low anxiety, high motivation and good adjustment to new situations	[44] f
Mental skills according to the psychological characteristics related to sports questionnaire	[45] f
Task-orientation, collectivism, goal-orientation	[46] m
Relations between psychological skills (mental toughness, coping, emotional control and confidence) and shooting effectiveness	[47] Egyptian m university players
Competitive anxiety is related to psychological performance in sports	[48] Beach handball

45.1.2 Position-Specific Psychological Demands

45.1.2.1 Position-Specific Demands

Position-specific psychological demands have been studied in other sports such as netball [4] and soccer [5] and have raised interest in handball as well.

Kajtna et al. [49] found that high-level goalkeepers function in a rather action-orientated way when it comes to coping with failures, while Vasconcelos-Raposo et al. [27] found significant motivational differences between positions for male Portuguese players. Descriptive statistics showed higher levels of ego-orientation for pivots/line players and lower levels of task-orientation in centre backs than in other positions. Vasconcelos-Raposo et al. [27] found a tendency for differences between positions with all-rounders > half backs > goalkeepers > wings > pivots/line players > centre backs for task-orientation and half backs > pivots/line players > wings > goalkeepers > centre backs > all-rounders for ego-orientation. Most studies so far have only assessed performance-relevant psychological factors for team handball in general without differentiating between positions. Table 45.3 shows defined position-specific demands in handball.

While psychological demands are seen as a factor which is crucial to performance for goalkeepers, the exact composition of a goalkeeper's psychological profile has not yet been specified [49]. In addition, studies do not always test the relevant psychological factors. Kajtna et al. [49] found less successful goalkeepers better in several psychological factors than more successful goalkeepers. Kajtna et al. [49] did not evaluate concentration, fear or aggression; however, it was evident that successful goalkeepers did not think about failure as much and as long as less successful goalkeepers.

Table 45.3 Position-specific psychological aspects

Position	Performance-limiting psychological factors	Study
Wing	Speed of decision	[36] f
Half back	Lowest results for psychoticism	[25] m and f
Centre back	Psychological stress tolerance can be considered crucial due to intensity of play	[50] m
Pivot	Psychological stress tolerance can be considered crucial due to intensity of play	[50] m, [51] m, [52] f
	Pivots are emotionally stable. Neuroticism level of male and female players does not differ significantly	[25] m and f
Goalkeeper	Anticipation expertise	[53], m
	More successful goalkeepers have slower response times in complex situations, simple selective tasks and complex tasks with visual orientation, but they thought shorter about mistakes they had made	[49] m elite Slovenia
	Confidence, courage, instinct, concentration	[54] m

Table 45.4 Position-specific demands in female team handball

Position	Performance-limiting psychological factors	Study
Wing players	Characteristic values and relation to performance for hope for success, fear of failure, net hope, total achievement motive (high), self-impediment (high), lack of activation (low), loss of focus (low), action-control after failure (low)	[55, 62, 63]
	High speed of decision	[36]
Half backs	Characteristic values and relation to performance concerning hope for success, total achievement motive (high), self-impediment (high), action-control after failure (low) and action-control while performing a task	[55, 62, 63]
Centre backs	Characteristic values and relation to performance concerning self-optimizing (high) and action-control while performing a task (high)	[55, 62, 63]
Pivots	Psychological stress tolerance can be assumed due to intensity of play	[52]
	Characteristic values and relation to performance concerning hope for success, net hope, self-impediment (low), loss of focus (by trend), action-control after failure (high by trend) and action-control after failure (high by trend)	[55, 62, 63]
Goalkeepers	Cognitive speed of action	[61]
	Lower scores in introversion-extroversion compared to other positions, goalkeepers are more introverted	[60] Youth elite
	Best performance in the psychological characteristics related to sports questionnaire	[65]
	Characteristic values and relation to performance concerning hope for success (high by trend), net hope (high), self-impediment (high), lack of activation (low), loss of focus, action-control after failure (low), action-control when planning a task (low by trend) and action-control when performing a task	[55, 62, 63]

This could suggest a need for high action-orientation after failure on that position. More studies researching position-specific psychological demands profiles are necessary to be able to select and train/coach players most efficiently [55].

45.1.2.2 Position-Specific Demands for Female Players

In female handball, only few studies regarding psychological characteristics [45, 56–58], let alone on the different positions [25, 36, 55, 59–63], have been undertaken so far, although literature suggests that female players differ from male players concerning this matter [45, 57, 58, 64] and positional differences are relevant to performance. Čavala et al. [60] found position-specific differences in female players with wings being the most extroverted followed by pivots/line players, backs and goalkeepers and a tendency for differences concerning psychoticism (pivots > wings > backs > goalkeepers) (Table 45.4).

Weber [62] calculated desired values for psychological factors in first–third German league teams (Table 45.5). It is noticeable that when

Table 45.5 Values for female model players at the 3rd German league (modified from [62])

Position	Performance factor[a]	Desired value	Estimated failure	*p*-value	*r*-value
	Hope for success	35.65	5.17	0.002	0.236
	Net hope	24.93	10.72	0.080	0.135
	Overall performance motive	47.15	6.92	0.005	0.212
Wings	Self-inhibition	12.14	4.30	0.043	0.154
	Lack of activation	7.07	5.28	0.001	0.255
	Loss of focus	4.17	3.90	0.001	0.254
	Action-control after failure	4.53	2.96	0.015	0.185
	Hope for success	34.24	6.17	0.026	0.178
	Overall performance motive	46.74	7.38	0.003	0.240
Half backs	Self-inhibition	13.16	4.94	0.001	0.254
	Action-control after failure	4.49	3.07	0.001	0.254
	Action-control while performing	8.84	2.50	0.054	0.153
Centre backs	Self-optimizing	64.16	11.99	0.083	0.184
	Action-control while performing	9.33	2.18	0.044	0.212
Pivots	Hope for success	34.72	6.47	0.076	0.196
	Net hope	25.61	11.37	0.090	0.187
	Self-inhibition	11.67	4.34	0.007	0.302
	Action-control after failure	4.45	2.71	0.044	0.221
	Self-optimizing	62.09	11.57	0.044	0.223
	Lack of activation	8.88	6.70	0.002	0.336
	Hope for success	34.38	7.15	0.029	0.240
	Net hope	24.86	13.57	0.025	0.245
Goalkeepers	Loss of focus	4.27	3.81	0.010	0.283
	Lack of activation	7.88	6.67	0.001	0.347
	Action-control while performing	8.93	2.39	0.031	0.235

[a] Only factors with sufficient *p*- and *r*-values are shown with $p < 0.1$ (tendency) and $r \geq 0.1$

planning a task, action-control does not seem to be relevant for any position [62].

Weber, Wegner and Popa [63] show descriptive statistics for the psychological factors on the positions in first–third German league (Fig. 45.1)

One particular factor which is connected to psychological aspects and which is showing differences between playing positions is handedness. In handball, right-handed players are often put on the left side of the court and left-handers on the right, since this leads to optimal angles when attacking and shooting the ball at the goal [38, 66]. Among female Austrian players, there are 88.2% right-handed, 8.3% left-handed and 3.4% ambidextrous players, while the dominant hand mostly is the throwing hand [38]. At the Handball-Supercup in 1987, there were up to three left-handers at a time on the court, which suggests a relevance of left-handedness to team performance [38].

Preference for one hand is connected to laterality [67]. In the overall population, there are 10% left-handers [38, 67, 68 with 10–13%]. Considering female population, Coren [69] found 90.9% right-handers, 6.8% left-handers and 2.4% ambidexters. For different kinds of sports (especially interactive sports), the frequency of left-handedness in the athletes differs from that in overall population.

Weber [62] showed that in different positions, players with different handedness are positioned in different percentages (Fig. 45.2), which partly also correlate with playing level (left-handers and ambidexters on right wing, both and left-handers on right back, ambidexters in the goal, no left-handers on the pivot position, right-handers on centre back). According to Weber [62], ambidexterity correlates with expertise in goalkeepers, while right-handedness correlates negatively with expertise. The fact that only right-handers

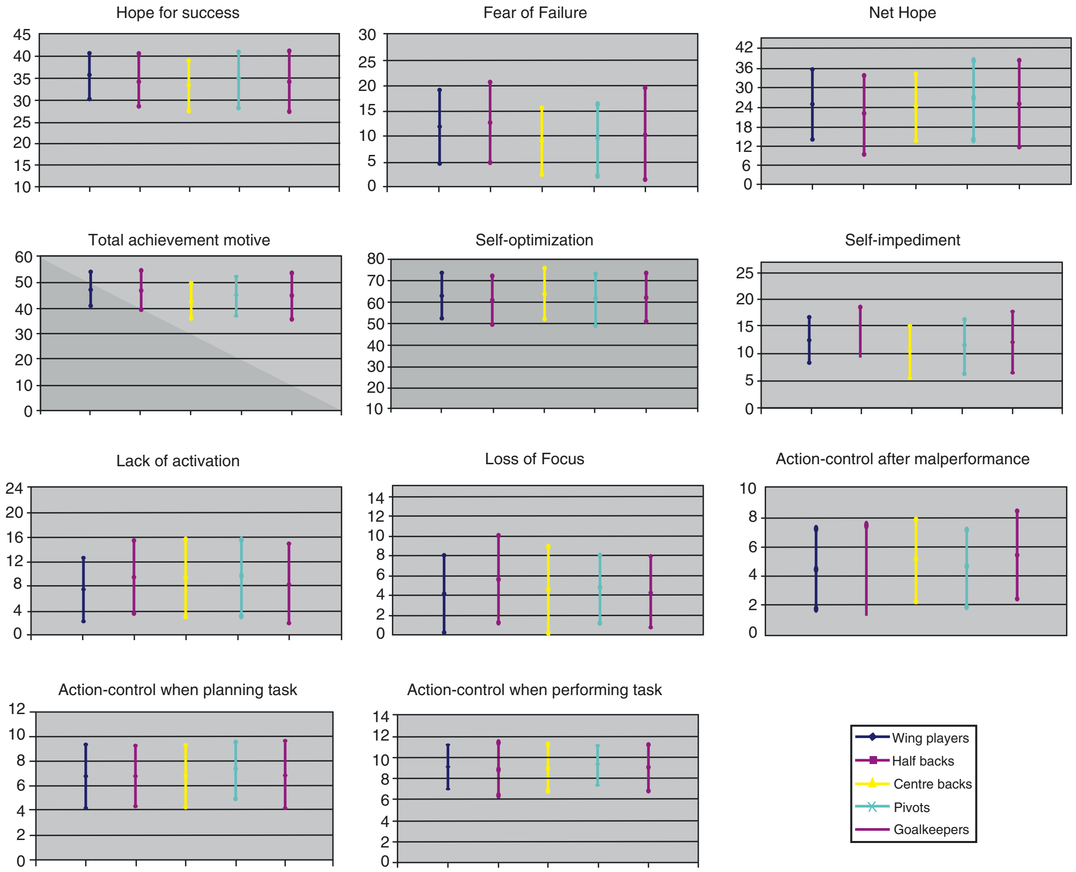

Fig. 45.1 Descriptive values for female players in first–third German league, confidence interval 0.95 with d_max ±3.25%, modified from [63]

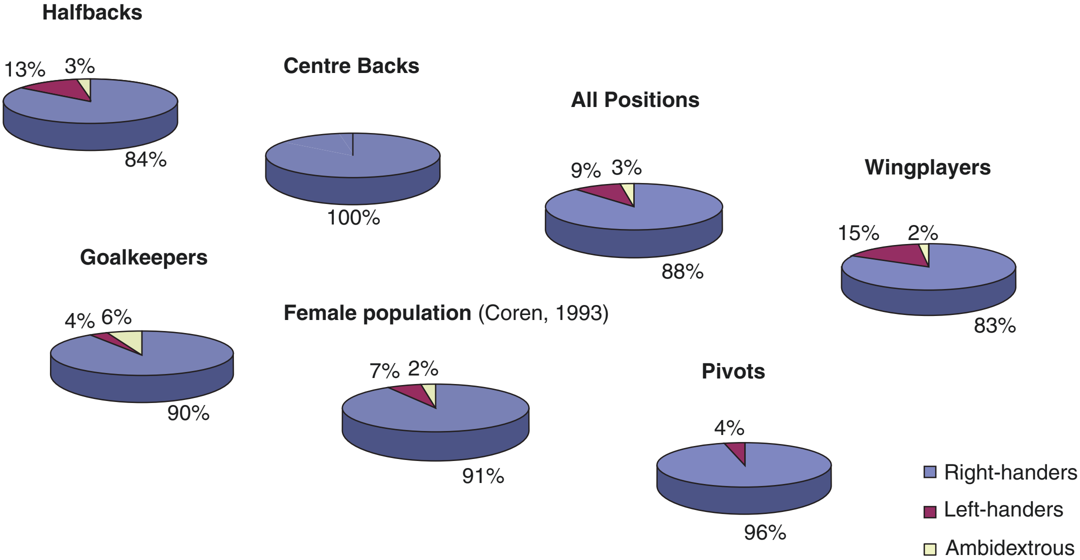

Fig. 45.2 Percentages of handedness on different positions and in female population, modified from [70] (Confidence-interval 0.95 with d_max ± 2.15%) *WP* wing players, *HB* half backs, *CB* centre backs, *P* pivots, *GK* goalkeepers

are positioned on centre back can be interpreted as preference for right-handers on this position since even when considering estimated failure, the percentage of left-handers undercuts that in female population. Playmakers should be state-oriented while performing a task, while this psychological characteristic is linked to right-handedness as well as high values in self-optimizing. State-orientation while performing is crucial for right-handed players on several positions. Weber [62] found only few correlations between psychological factors and expertise for left-handed players, while the left-handers showed homogeneous values for most psychological factors. There are particular values for action-control in players of different handedness at elite level (state-orientation while performing a task for centre backs, action-orientation after failure for right-handed goalkeepers).

Specialization for a position and position-specific selection with regard to psychological factors seems to be beneficial in adult female players [54]; however, psychological factors may change during adolescence, and specializing too early may impair optimal position-specific selection. Constitutional parameters and early selection are regarded controversially with some opposing early selection according to constitutional factors [70–72] and others supporting early selection according to constitutional factors [60], mainly as these factors can change during adolescence. After these potential changes, a player might be suited better for another position for which he or she then lacks the technical and tactical ability. Thus, psychological factors might be a better predictor than other performance factors, since conditional and constitutional factors are *poor markers for sport-selecting strategies* [12, p. 392]. Motivation might be a better predictor [12] as well as volition [13]. The age of specialization therefore has to be carefully considered. The "long-term handball development model" [70] recommends specializing at 16 years of age for boys, whereas Čavala et al. [60] recommend specialization at 13 for girls to promote optimum development of conditional and constitutional factors. There is a growing interest in specialization and selection according to psychological factors, and this aspect probably should and most probably will be further explored and researched in the following years.

45.1.3 Psychological Factors and Injuries

Handball is a fast and dynamic contact sport. Frequent collisions between opponents, high tempo, rapid changes of direction and jumps with hard landings lead to a high risk of injuries. Studies from the Summer Olympics in 2008 and 2012 have placed handball among the highest injury rated sports compared to other sports [73, 74]. In a comparison of injury rates in the German sport club system, team handball scored second after soccer [75, 76].

Whether or not psychological factors which may have an influence on injury risk and maybe on the phase of injury rehabilitation could be identified is an important question. Two different perspectives are focused within sport injury research: pre-injury and post-injury perspectives. The pre-injury focus is set on psychological factors that are related to injury risk and to interventions which can decrease that risk. The post-injury perspective is related to the rehabilitation process and on intervention strategies which facilitate rehabilitation and return to sport.

45.1.3.1 Psychological Factors and Predisposition to Injuries

The influence of psychological factors on injury incidence is discussed by several researchers [e.g. 76–78]. Competitive stress seemed to be the core variable to explain injury incidence. A potentially stressful sports scenario (e.g. competition, important practice, poor performance) can contribute to injury depending on how threatening the player perceives the situation to be. A situation perceived as threatening increases the state of anxiety, which causes a variety of changes in focus of attention and muscle tension [79].

To better understand injury risk from the psychological perspective, two models are described:

(1) the biopsychosocial view of injury [77] and (2) the model of stress and athletic injury [80].

(1) The *biopsychosocial view of injury* [77] is developed to explain psychological reactions to sport injuries from different perspectives. Injury characteristics (e.g. severity, type) and socio-demographic characteristics (e.g. age, gender) will influence biological (e.g. immune functioning, circulation), psychological (e.g. affect, behaviour) and social/contextual factors (e.g. social network, life stress). In turn, these three factors will have an indirect effect on sport rehabilitation outcome (e.g. functional performance, readiness to return to sport).

(2) The *model of stress and athletic injury* [80] is the most recognized theoretical framework to explain psychological reactions to sport injuries [81]. Injury risk is influenced by the athlete's appraisal of a potential stressful situation and the magnitude of stress response. This bidirectional relationship is influenced by four different factors: personality, history of stressors, coping resources, and psychological skill interventions. These factors mediate the stress response and injury risk.

Personality traits are a main category of psychological risk factors. Traits that increase injury risk are anxiety [82], worry [83] and stress susceptibility [84]. On the other hand, athletes with adaptive personal traits such as hardiness [85], optimism [86] and self-confidence [87] seemed to be injured less often than other athletes [81]. The relationship between personality and stress response seems to have an indirect effect on injury rates. Additionally, social support serves as a mediator of injury risk. Life stress will create a higher risk for athletes with low coping skills and low levels of social support [79].

The history of stressors means that certain life events, daily hassles or the experience of previous injuries might increase injury risk. High level of life event stress (positive and negative) increased injury risk among junior soccer players [88]. The impact of hassles on injury risk has been investigated only in a couple of studies [81]. Previous injury experience might increase injury risk because of the insufficient recovery state or lack of psychological preparation.

Coping refers to behavioural and cognitive strategies to deal with the demands of the competitive situation. Problem-focused strategies are directed towards the demand itself, whereas emotion-focused strategies are related to the emotional reactions [89]. Coping and injury risk is interrelated. Adaptive strategies can be used to influence the athlete's appraisal of stressful situations and to decrease the magnitude of stress response.

Finally, *psychological skill interventions* can change inefficient stress appraisal routines, muscle tension or the magnitude of stress response [80]. Those techniques can be cognitive restructuring, confidence training, realistic goal setting as well as relaxation skills, imagery or distraction desensitization. The intervention programme should be applied by a professional sport psychologist. Empirical studies have shown positive results with fewer injuries in the intervention group compared to the control group [81].

These theoretical frameworks demonstrate the high incidence of personality factors, resources or coping skills on injury risk. Athletes at higher risk can be characterized by combinations of high trait anxiety, high life stress, low psychological and coping skills, low social support, and high avoidance coping. On the other hand, athletes at high risk can profit from stress management training [79]. Ivarson [81] has put together several studies with Swedish soccer players to analyse the impact of stress on injury risk and the effectiveness of intervention strategies. These findings could easily be transferred and implemented in handball.

Weinberg and Gould [79] draw several important conclusions from these findings: identify stress-prone athletes, educate your athletes in stress management techniques and coping skills and develop a system of social support within your team.

45.1.3.2 Psychological Reaction to Injury

Injury in competitive sports is inherently a risk factor. It is important to understand the psychological reactions to injury. Two post-injury perspectives are focused in research: (1) the psychological reactions to injury and (2) psychological factors that facilitate the rehabilitation process and return to sport [79, 81].

The reaction to an injury seems to be very individual and does not follow a stereotypical pattern. Some athletes perceive the injury as a disaster, while some might perceive it as a relief to get out of strenuous practice or to have an acceptable excuse to avoid stressful situations [79]. Common reactions are sadness, grief, fatigue, depression and anxiety. Most of these emotions could also be present during the injury rehabilitation process.

Weinberg and Gould [79] describe some typical responses to injury. Some athletes may experience an *identity loss* following injury. They feel that an important part of themselves is lost. Coaches can help athletes when they provide a supportive environment during the rehabilitation process. *Lack of confidence* can be the result of the inability to practise or compete. High level of *fear and anxiety* is experienced when there is a risk of reinjury or when it is not clear whether recovery to full performance strength will be achieved. Lowered confidence can result in *performance decrements* because of missing practice or a maladjustment of the athlete's expectations. The impact of *group processes* can be twofold. Injured players can profit from group cohesion during rehabilitation. On the other hand, the competition for open positions by other players may be a stressor for the injured athlete.

Coaches should therefore be aware and sensitive to these issues when dealing with injured players. Warning signs of poor adaptation are feelings of anger and confusion, obsession with the question of when one can return to play, withdrawal from significant others, denial (e.g. "The injury is not a big deal") or rapid mood swings [90].

45.1.3.3 Psychological Factors in Rehabilitation and Return to Sports

The return to sport after injury is based on a solid rehabilitation that includes medical therapy as well as psychological strategies. Findings of a meta-analysis [91] concerning surgery of the anterior cruciate ligament show that approximately 90% of patients achieved successful outcomes in terms of impairment-based measures of knee function. But only 40–50% of athletes return to competitive sports 1 year after surgery; about 33% are not able to return to previous level of competitive performance. It seems that factors other than knee function contribute to the return to sports. At this point, a better understanding of contextual factors (such as fear of reinjury and lifestyle change) is needed for a successful return to sports [92].

Objective as well as subjective criteria count for a good prediction to return to sports again [93]. Objective criteria are based on medical expertise and functional testing (e.g. joint stability, muscle strength, proprioception, comparisons to the "non-injured" side, hop tests, agility tests, etc.). Subjective criteria are mainly based on psychological factors like fear of pain, fear of reinjury, kinesophobia or deficient confidence. Kinesophobia is a term used in the context of rehabilitation medicine and physical therapy. It refers to the patients' fear of moving because of the injury and can be a factor in increased time to return to participation in pre-injury activities [94, 95]. Kocher et al. [96] pointed out that subjective criteria may be more important for the return to sports than objective findings.

A good prediction for psychological readiness is the ACL-RSI-scale (anterior cruciate ligament return to sport after injury scale). Three elements are correlated with returning to sports in the literature: emotions, confidence in one's performance and evaluation of risk [97, 98]. Cross cultural adaptation studies show a good evidence for the return to pre-injury sport activity [99, 100].

Psychological rehabilitation can be enhanced in a structured educational process. Hermann and Eberspächer [101] recommend a holistic approach to rehabilitation. Physical therapy should be accompanied by psychological strategies to facilitate recovery from injury.

Hermann and Eberspächer [101] follow a four stage model to explain the psychological rehabilitation process. The first stage, *the acute phase*, includes the incidence of injury and in many cases surgery. Educating the athlete about their injury is the first step. Emotional disturbances can also be reduced by informing the athlete about how much control they can earn over their injury when they follow the rehabilitation programme. Mayer and Hermann [102] imply that short after injury or surgery small movements and first steps of mental training should be commenced.

The second stage, *the transition phase*, is used to find access to the rehabilitation programme. Basic movements—depending on the severity of the injury—are part of the recovery plan. The third stage, *the phase of athletic rehabilitation*, follows the phase of sport-unspecific training units and includes the initiation of more sport-specific training units. The fourth stage, *the phase of preparation for competition*, is used to monitor the athlete during training routine to become stable for the demands of competition. This phase is often not supported by competent personnel. Many athletes tend to overestimate their physical and mental state during rehabilitation. The risk of reinjury is increased when athletes overdo training or return to competition too early.

Weinberg and Gould [79] use a three-stage model to describe the rehabilitation process. In the *injury or illness phase*, instant support for the athlete is needed to help coping with the emotions. In the *rehabilitation and recovery phase*, it is important to maintain motivation and adherence to the recovery process. Working closely with the athlete after setbacks, as well as setting goals for the upcoming recovery period, is useful in this phase. The third phase, *return to full activity*, does include to preparation for physical readiness as well as the mental stability to return to normal functioning in full training and competition.

The authors emphasize psychological support as a tool for the recovery process. Several psychological interventions and procedures should facilitate the rehabilitation process. These include a set of short-term goals, educating the athlete about the injury and the recovery process, teaching specific psychological coping skills, preparing the athlete to cope with setbacks, fostering social support and learning (and encouraging the athlete to learn) from other injured athletes.

Additionally, there are reports of common mental disorders, depression and anxiety in handball players. Also, there seems to be a connection between injury and common mental disorders. A recent study form Denmark has shown both professional Danish football and handball players are subject to common mental disorders, anxiety and depression during and also following their playing career. Severe injury increased the risk for common mental disorders by 20% in football players and 50% in handball players [103]. These findings do even further emphasize the need for psychological coaching in sports and especially after injuries, but also in order to provide retired players with tools to face challenges in the "post career" period.

The role of a sport psychologist in the rehabilitation process is to monitor the stepwise programme of recovery in cooperation with the coach and the medical team. Weinberg and Gould [79] identified four different psychological strategies (goal setting, self-talk strategies, imagery and relaxation training) that influence the rehabilitation adherence of athletes.

Goal setting strategies are necessary to develop a sense for the rehabilitation process. Goals should be specific, measurable, attainable, realistic and time phased (SMART). *Self-talk strategies* are helpful to enhance positive motivation. The athlete should learn to stop negative thoughts ("I will never make it back in the team again") and replace it with a realistic, positive self-talk ("Just one more step, I can do it"). *Imagery* is the process of creating or re-creating an experience in one's mind. It can be a recall of a motor skill or the visualization of a positive experience that can facilitate the return to competition. *Relaxation training (*progressive relaxation, autogenic training, yoga or biofeedback) may assist in building up skills to get control over tension or relaxation.

In summarizing the psychological perspective of injury risk and rehabilitation, these perspectives should be used to optimize rehabilitation in handball. The psychological aspects of injury should provide ideas for the onset of injury preventive strategies as well as for strategies in the rehabilitation process following injury. There is a lack of empirical data on how to deal with an injury. Quite often, only the medical aspects and physiotherapy are focused in the rehabilitation process. Psychological strategies should be implemented more often to help the athlete to get along with fear, misunderstanding and helplessness after injury.

Psychology offers different strategies to enhance recovery. They educate athletes for a better understanding of the rehabilitation process; they help building up resources and self-efficacy to regain the mental stability necessary for competition. At the same time, psychological factors are crucial to match performance. Possible implementations of psychological interventions (mental training, selection) in the areas of application discussed above (position-specific training, injury disposition, return to sports, match performance) will be a subject to upcoming studies.

45.2 Take-Home Message

Research interest in the effect of psychological factors on handball performance is growing.

Most important performance-relevant factors that have been identified in studies so far: mental toughness, cognitive skills, personality traits, precompetitive anxiety, task- and ego-orientation, motivation, volition, emotion, coping, concentration, perception, anticipation, decision-making, handedness, intuition and action-control.

There are position- and gender-specific differences regarding psychological factors.

Psychological factors can be used to select players for a team or playing position.

Psychological factors and personality traits affect injury risk and return to sports.

Biological, social and psychological factors influence the outcome of rehabilitation after injury.

The stress response to an injury is regulated by psychological factors.

Psychological skill interventions and mental training can facilitate the rehabilitation process.

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