Francesco Feletti
Editor

Extreme Sports Medicine

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Foreword

Extreme sports are no longer a gimmick or a niche field. Despite of the inherent risks, extreme sports have evolved tremendously and gained enormous popularity over the past decades, involving both elite and recreational athletes. The impressive film footage generated by extreme sports participants including breathtaking stunts (and spectacular crashes or near misses) has attracted not only sports fans but also major television networks, their audiences and advertising, with its associated financial gain. To the general public the challenge and associated risks may seem unreasonably high, and yet each event may be the culmination of hours of training and preparation, similar to every other professional and more common sports pursuit.

As more and more people are enjoying extreme sports, unfortunately increased numbers are becoming injured as a result. Future research is progressing alongside the sports development to allow the sports mechanisms, injury patterns, and predisposing factors to be better understood. It is the hope of all researchers and athletes involved to make the sports safer without detracting from its adventurous nature. Researching extreme sports requires thorough understanding of the activities, preferably from within, as every small detail related to the technique and equipment utilized is instrumental to the global picture.

Dr. Feletti's passion as a physician and as an extreme sports athlete is transparent throughout this comprehensive collection, spanning over many medical subspecialties and fields, which were not previously discussed or presented in this context. I believe that this will be a great source for the health-care provider, both for the understanding and when approaching the extreme sports athlete.

Boulder, Colorado Omer Mei-Dan

Preface

Extreme sports medicine is a rising discipline focused on medical commitment in the field of extreme sports.

Extreme sport does not just mean *sport taken to its extreme extent*. Extreme sports are to be strictly defined as sports – *physical activity requiring specific skills* – that expose participants to the risk of serious injuries or death in the case of mismanaged execution.

However, a widely shared definition among scholars does not currently exist. Risk plays an undeniable key role when defining an extreme sport, but stating how much risk is required for an activity to be considered “extreme” may be debatable. The perceived risk may prevail over any actual danger.

Thus, many activities involving high speed, height, or extreme strain are often generically ascribed to extreme sports independent of their real level of danger.

Several remarkable features highlight extreme sports compared to traditional ones:

- People’s drive to overcome their own limits and to break free from their daily routine.
- The role of environmental and meteorological circumstances since many extreme performances depend on natural forces and are undertaken to challenge physical laws; environmental variables are in sharp contrast to the controlled circumstances of traditional sporting events.
- The importance of high-tech equipment and the implementation of innovative approaches to the specific performance conduct (e.g., particular life pace management in solo oceanic sailing races).
- A marked influence on the collective imagination and the attraction of media interest – a strong appeal that is exploited in marketing campaigns and by the fashion world.

Albeit with some exceptions, extreme sports also share the following features:

- Their solitary nature, usually being practiced alone or in remote areas.
- A greater attention to aesthetic criteria rather than traditional quantitative parameters (distance, time, score, etc.) when assessing performance to such an extent that competition is not at the core of many of these activities.

Extreme sports have never been so popular. Today, they are practiced by millions of people worldwide, and this is a phenomenon that medicine needs to face.

The fact is that medicine has, so far, only been involved in these sports on a limited basis, dealing mainly with their sudden onset injuries.

However, overuse injuries and illnesses, specific psycho-physical training, preparation and rehabilitation programs, and specific diet and supplements also need to undergo evaluation.

Professionals working in the field must gain the knowledge and skills needed to intervene in remote and adverse environments.

A *multidisciplinary approach* involving many medical specialties – physiotherapy, psychology, physiology, and branches of engineering, ergonomics, physics, and materials science – is necessary.

Research encounters many difficulties. It requires distinct methods. On the one hand, extreme sports participants may be reluctant to take part in medical research because of their cultural conditioning. On the other hand, pursuing these studies is difficult due to the many variables involved, and the assessment parameters adopted in traditional sports may not be adequate for many extreme ones.

For instance, the injury rate appraisal in terms of hours practiced may not be completely accurate since many of these sports are intermittent – the time in the field is not necessarily spent in action.

Consequently, medicine should approach extreme sports in a new, more meaningful way in terms of research, support, prevention, diagnosis, and treatment.

This compendium includes the open contribution of the most authoritative experts in key fields of extreme sports medicine worldwide.

This book is not structured systematically; the authors have been allowed to discuss their subjects freely. The editor took this approach deliberately due to the vastness of the theme and the variety of relevant subjects. This pioneering work conveys the energy of a new scientific field that will definitely continue to develop and expand into the future.

Ravenna, Italy Francesco Feletti
May 2016

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About the Editor

Dr Francesco Feletti is an extreme sports medicine expert.

He currently works as a radiologist at the *S. Maria delle Croci* Hospital in Ravenna, Italy.

In collaboration with the *Politecnico di Milano* University, he conducts cutting-edge academic extreme sports medicine research, and in 2013 he co-founded the *ExtremeSportMed* international scientific society.

He is a faculty member and lecturer at the International Extreme Sports Medicine Congress, located in Boulder, Co, USA and the ambassador of that congress to Europe.

His 20-year international athletic experience in many extreme sports and background as a windsurfing, kitesurfing and sailing instructor give him unique insight into this world.

The Use of "Accident" and "Incident"

An editorial decision was made to allow authors to use the term "accident" rather than "incident" as they saw fit throughout the text.

In many industries, government agencies, legal and scientific fields, the term "accident" is not used, or its use is debated because it could imply that the event was unavoidable (i.e., a chance occurrence or an "act of God") and therefore could not be prevented.

This is the reason why the *British Medical Journal* (BMJ) banned the term "accident" in an editorial in 2001 [1] consequently arousing fervent discussion [2].

However, in some ambits such as in aviation, "accident" and "incident" are both currently used to mean different feature events with the aim to highlight such aspects that may practically affect risk management [3].

In particular within this context, both terms refer to events that may be subjected to preventative measures; however, "accident" is adopted for any occurrence actually resulting in injuries, material damages, or fatalities, while "incident" more generically refers to any occurrence that affects or could affect safety [3].

The term "accident" is still common in scientific medical papers [4], and it is widely used in medical literature regarding extreme sports in particular.

Extreme sports medicine requires special methods and terminology, and, as already observed, the choice of the most appropriate terms in the field of extreme sports injury prevention may be particularly complex [2] due to the special features of these activities.

Within the sphere of extreme sports medicine, the use of both "accident" and "incident" may therefore help to distinguish events of different features. What is more, the use of "accident" could be difficult to replace.

In particular, the term "accident" is often preferred for an event which:

- actually *results in unpleasant consequences* such as material damages, injuries, illnesses, or death;
- happens unexpectedly and unintentionally as a consequence of a complex chain of events which includes environmental and weather conditions, equipment failures, or human error.

As such, "accident" may be appropriate to refer to injuries which take place while riding or flying specific extreme sports vehicles or crafts such as boards, parachutes, wingsuits, mountain bikes, etc.

Alternatively, the term “incident” more generically refers to an event which:

- *affects or may affect people’s safety*, near misses included;
- is not part of standard performance execution, either a *result of intentional athlete conduct* or a repercussion of misjudgment (i.e., as a consequence of tiredness or of temporary mental impairment caused by extreme environments such as e.g., nitrogen narcosis in extreme diving).

Therefore, in the specific setting of extreme sports, the implicit unpredictability of the term “accident” lends itself to the examination of complex events stemming from the wide range of variables involved, many of which are difficult to predict such as environmental and weather-related factors.

The use of the term “accident,” however, does not mean that sportsmen are at the mercy of fate; there is still the possibility of adopting preventive measures to minimize risks or break down the chain of events and intervene. This is one of the goals of extreme sports medicine.

For the above-mentioned reasons, the use of “accident” has been accepted in this compendium, but the authors were free to use the terminology that, in their opinion, was most suitable to any specific subject.

We think that, regardless of the terminology adopted to refer to injury events, the possibility of intervening in different ways to prevent extreme sports injuries is evident in each chapter and in the work as a whole.

References

1. Davis RM, Pless B. BMJ bans “accidents” Accidents are not unpredictable. BMJ 2001;322:1320. doi:10.1136/jech.2003.017715. PMCID: PMC1733021.
2. Pless IB, Hagel BE. Injury prevention: a glossary of terms. J Epidemiol Community Health. 2005;59(3):182–5.
3. International Civil Aviation Organization. International standards and recommended practices. Annex 13 to the Convention on the International Civil Aviation. Aircraft accidents and incidents investigation. http://www.cad.gov.rs/docs/udesi/an13_cons.pdf.
4. PubMed. US National Library of Medicine National Institutes of Health. http://www.ncbi.nlm.nih.gov/pubmed?term=(Accident%5BTitle%5D)%20AND%20(%222015%22%5BDate%20-%20Completion%5D%20%3A%20%223000%22%5BDate%20-%20Completion%5D). Accessed on 5 April 2016.

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Part I

Medicine in Extreme Sports

Psychology and the Extreme Sport Experience

1

Eric Brymer and Susan Houge Mackenzie

1.1 Introduction

Over the past 40 years, the popularity of extreme sports has grown exponentially. This phenomenon coincided with a significant shift in sport and leisure participation choices; participation rates in 'extreme' or adventure sports far outstripped the growth rates of many traditional sporting activities in recent decades [1, 2]. According to [3], this phenomenon should not be considered 'a "flash in the pan"', but rather a significant shift in participation choices resulting from people's search for enhanced meaning in their lives through novel outlets. From this perspective, extreme sports provide an antidote to manicured existences constrained by artificial regulations that serve disconnect people from their human potential.

Academic literature remains fragmented regarding the psychological experience(s) of extreme sport participants. This is due in part to a lack of common terminology and operational definitions. Whilst the term extreme sport is well known, there is still confusion about what constitutes an 'extreme sport'. For example, terms such as 'whiz sports', 'free sports', 'adventure sports', 'lifestyle sports', 'alternative sports', 'action sports' and 'aggro sports' are often used interchangeably with extreme sports to describe the same type of activity. At times the term extreme sport has been used to refer to nontraditional competitive youth sports, such as skateboarding and BMX. At other times it has been used to refer to activities requiring little skill or expert knowledge, such as commercial rafting and bungee jumping. In some contexts, the term extreme sport is a synonym for a variety of adventure experiences such as mountaineering, climbing, skiing and kayaking. Moreover, there is debate concerning whether extreme sports are necessarily solo activities or if they can include team-oriented pursuits such as paintball and white-water rafting.

The ramifications of this conceptual cross-pollination include the development of imprecise definitions, models and theories that do not fully reflect the lived experience of diverse participants. For example, researchers might extrapolate results from a study on bungee jumping to explain the psychological nature of those who participate in BASE (buildings, antennae, space, earth) jumping, thus assuming that BASE jumping and bungee jumping fall at different places along the same continuum. Similarly, a study of young skydivers that identifies thrill seeking as a primary motivation might incorrectly extrapolate that all skydivers participate to experience thrills.

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In this chapter, we define extreme sports as *independent adventure activities where a mismanaged mistake or accident is most likely to result in death* [4]. Activities that typify this definition include BASE jumping, extreme skiing, waterfall kayaking, big-wave surfing, high-level mountaineering and 'free solo' climbing. BASE jumping is a parachute sport where participants jump from solid structures (e.g. bridges, buildings, cliffs) that are only a few hundred feet from the ground [5, 6]. In extreme skiing, participants ski down sheer cliffs where a fall would most likely result in an out of control tumble. Extreme kayakers tackle waterfalls rated as either 'portages' or the most difficult to navigate (i.e. grade six) on the international white-water grading system [7]. Big-wave surfers ride waves over 20 feet tall, a pursuit which has even resulted in deaths of surfers renowned for their competence [8]. High-level mountaineering takes place above the death zone (8000 m) wherein mountaineers' bodies are extended to their limits [9]. Free solo climbing involves climbing without rope protection or other aids on high rock structures, such as the Half Dome in Yosemite [9].

1.2 Traditional Perspectives on the Psychology of Extreme Sports

Until recently, prevailing assumptions presented by researchers and theorists presupposed that people undertaking extreme sports were abnormal individuals that had a 'death wish', were motivated strictly by the desire for thrills and risk-taking and/or were 'wired' differently to the general population. Participants were generally portrayed as selfish young adults, generally males, 'fascinated with the individuality, risk and danger of [extreme] sports' [10]. Media and advertising representations have mirrored these presuppositions [3, 11–13]. The assumption underlying these portrayals is that participants are risk seekers, who may be unskilled, with a desperate desire to connect with the image of glamour associated with extreme sports. Researchers and popular press have argued, why else would someone willingly undertake a leisure activity where death is a potential outcome? Proffered explanations suggested that participants were 'crazy people' with 'deviant' traits that predisposed them to deviant risk-taking behaviours, due to deep, unfulfilled psychological needs and/or adrenaline addictions [14–21]. These assumptions have even led some theorists to assume that extreme sport participation is akin to drug addiction or other socially deviant behaviour.

The increase and differentiation in extreme sport participation also gave rise to psychological theories and models seeking to explain these seemingly 'paradoxical' pursuits. Some of the dominant theories that are still used to address extreme sport motivations include sensation seeking [22, 23], psychoanalysis [24], type 'T' personality [20], reversal theory [25, 26] and edgework [27]. The following sections briefly outline and critique these theoretical assumptions.

1.2.1 Sensation Seeking

Sensation-seeking theory explains involvement in extreme sports through a personality trait that causes some individuals to seek out higher levels of novel sensations. Therefore, individuals 'born with a general sensation seeking motive' are more likely to seek risks, such as those inherent in extreme sports [28]. Sensation-seeking theory seeks to explain why some individuals seem to have an inherent need to continually search for risky, complex or novel experiences [22, 29]. Zuckerman defined sensation seeking as 'the seeking of varied, novel, complex and intense sensations and experiences, and the willingness to take physical, social, legal, and financial risks for the sake of such experiences' [28]. This theory postulates that individuals with a sensation-seeking trait require an arousal level that is higher than nonsensation seekers in order to maintain an optimal level of stimulation [30, 31].

There are four different types of sensation-seeking behaviour proposed in this theory: thrill and adventure seeking (TAS), experience seeking (ES), boredom susceptibility (BS) and disinhibition (DIS). Psychological scales have been developed to measure the extent to which individuals are positively or negatively inclined on each of these behaviour types. In order to holistically measure the sensation-seeking trait, an individual's score on each of these scales is cumulatively summed to give an overall sensation-seeking score (SSS) [29] The TAS scale refers to an individual's need to seek out risky and exciting sports or other activities and is the scale most often associated with extreme sports. The ES scale relates to the seeking of sensations through the mind or senses and the need for nonconformity. The DIS scale measures a person's need for social stimulation and search for experiences that might produce experiences of disinhibition. The BS scale refers to an individual's aversion to monotony and general experience of restlessness [30].

Numerous studies have been conducted on sensation seeking and 'extreme sports' [32, 33]. However, two factors often cloud the interpretation of results: diverse definitions of extreme sport and the a priori assumption that participation is predicated on risk-taking. Many of the sports in these studies do not meet the definition of extreme sports provided herein, and those that do fit this definition have inconclusive findings.

For example, a study by Goma [34] investigated alpinists ($n = 27$), mountaineers ($n = 72$), general sportspeople who undertook adventure sports such as white-water kayaking and caving but that were not related to mountaineering ($N = 221$) and individuals not involved in an adventure sport ($n = 54$). Goma considered alpinists to be extreme sportspeople with regard to their potential for death during this activity. The author found no significant difference between alpinists and either the mountaineer group or the general sport group terms on any of the sensation-seeking scales. However, the mountaineer group scored significantly higher than the general adventure sport group for both TAS and ES. This result suggests that extreme sport participants do not have higher sensation-seeking tendencies than 'non-extreme' adventure participants. However, the fact that the mountaineering group, who were not considered to be extreme sport athletes, scored significantly higher in TAS and ES than the general adventure sport group might suggest that the concept of sensation seeking, if at all useful, has a ceiling effect.

Slanger and Rudestam [35] examined sensation-seeking differences amongst participants in extreme, high-risk and traditional sports by comparing rock climbers, skiers, small-plane pilots and white-water kayakers with traditional sport participants (e.g. bowlers and gym-based fitness participants). In line with the definition in the current chapter, the proposed difference amongst groups was whether or not the likely consequence of an error was death. The study found no significant differences amongst the extreme-, high- or low-risk groups. The authors reasoned that these findings might reflect a number of factors. One conjecture was that sensation-seeking theory was not useful in differentiating between extreme sports and non-extreme sports. An alternative interpretation was that the theory is valid, but the scales may need further refinement to reflect individual differences in sensation seeking.

Sensation-seeking explanations might be useful to explain certain patterns of behaviour or aspects of high-risk sport participation, but this theory may not holistically account for the motivations of extreme athletes. Sensation seeking may indicate potential interest in 'high-risk' sports, but the trait may not necessarily predict involvement in an extreme sport. The mixed results of sensation-seeking research suggest that participation in extreme sports may be motivated by a range of factors in addition to, or separate from, sensation seeking.

1.2.2 Reversal Theory

Reversal theory [25, 36] is a general theoretical model of motivation and emotion, which posits the existence of opposing *metamotivational* states. *Metamotivational* states are frames of mind, or higher-order motivation levels, that determine how a person interprets their situation at any given time. A metamotivational state can be conceptualised as a proverbial pair of rose-coloured glasses [25]; a person always 'sees' or, more aptly, *feels* an experience in the context of their dominant metamotivational lens. Changes in an individual's mood, motivations and emotional experiences are instigated via regular alternations, or *reversals*, between these opposing metamotivational states. Although there are four pairs of opposing metamotivational states, the majority of reversal theory research in extreme sports has focused on the telic/paratelic states. These states are considered highly relevant to extreme sports as they provide an explanation as to why people interpret intense emotional arousal in very different ways, such as feeling excitement versus anxiety in the same external situation.

The *telic state* is primarily serious, goal-oriented and arousal avoidant, whereas the *paratelic state* is characterised as spontaneous, playful and arousal seeking [37]. In the telic state, current activity is seen as a means to an important end beyond the present moment, and thoughts are oriented towards planning for the future [38]. Excessive arousal results in feelings of anxiety or fear, whereas low arousal is relaxing and pleasant. In the paratelic state, arousal levels are experienced in direct opposition to the telic state pattern. In this playful state, activities are pursued as ends within themselves, and attentional focus is absorbed in the process-oriented goals of the activity. High arousal is experienced as excitement, whereas low arousal is boring.

Reversals between the telic and paratelic states are contingent upon the presence or absence of 'protective frames' [39]. As the name implies, a 'protective frame' provides feelings of protection from the presence of danger (e.g. due to confidence in oneself, others or equipment). When the protective frame is active (in the paratelic state), heightened arousal and challenge are experienced as exciting; when the protective frame is lacking (in the telic state), heightened arousal is experienced as anxiety. Although reversal theory is more state than trait based, individuals are thought to have dominant states that they tend to reverse into more often than others. For example, individuals who spend more time in serious, telic states are 'telic dominant', whereas individuals who tend to operate in playful, paratelic states are 'paratelic dominant'.

Investigations of paratelic dominance amongst athletes have supported the validity of this model. Studies by Kerr et al. [26] generally support the hypothesis that participants who regularly participate in sports deemed risky are arousal seekers (i.e. paratelic dominant). For example, significantly lower levels of arousal avoidance were found amongst surfers, sailboarders, motorcycle racers and parachutists in comparison to marathon runners, weight trainers or the general public [26]. Shoham et al. [40] also documented low arousal avoidance (i.e. paratelic dominance) amongst skydivers, rock and mountain climbers and deep-sea divers ($n = 72$). However, these studies did not explicitly differentiate between extreme- and high-risk sports, and as a result, extrapolating findings to participants in typical extreme sports might not be appropriate. Further, one issue that cannot be addressed by these studies is whether participants entered their sports with this disposition or whether they learned to enjoy high arousal as a result of participation. Thus, the issue of initial participation motives remains.

Recent research in reversal theory has further expanded this somewhat narrow view of extreme sport participation. For example, Kerr and Houge Mackenzie's [41] in-depth qualitative study of adventure sport experts highlighted the multifaceted nature of participant motivations. Experts identified diverse motives that included goal achievement, connection to the natural environment, social motives and pleasurable kinaesthetic sensations (from moving through water or air), in addition to more widely discussed motives, such as escape from boredom, risk-taking, pushing personal boundaries and overcoming fear. The authors concluded that motivations extended beyond excitement or thrill-seeking explanations and identified the need for more comprehensive models of participation motives.

1.2.3 Edgework

Edgework describes social factors that stimulate the desire for voluntary risk-taking and the sensations and feelings resulting from these experiences [42]. It also highlights diverse motives for voluntary risk-taking, such as opportunities to feel physical mastery, personal control, self-sufficiency and efficacy, which are often lacking in modern societies. The term edgework derives from an individual's desire to explore the edge or limits of their own control across a range of contexts [43]. Some individuals 'experience intense highs' and perceive heightened control over their lives, immediately after surviving events that push the edge of their psychological and physical limits. Edgework activities are those that involve a 'clearly observable threat to one's physical or mental well-being or one's sense of an ordered existence' [44]. The edge represents a slim boundary between opposing states such as life and death, chaos and order and consciousness and unconsciousness [42].

Research in edgework has demonstrated that negotiating various 'edges' (e.g. edge of competency/control) was a primary motivation in adventure activities and that edgeworkers attempted to identify their 'performance limits' by pushing physical and mental limits [44]. Continuous edgework inherently required continual rebalancing of challenges and skills in order to maintain this 'edge'[44, 45]. Edgework experiences were characterised by feelings of self-actualisation, altered sensory perceptions, feeling of 'oneness' with key objects, 'hyperreality' and the inability to fully articulate the experience [44]. Lois' [43] longitudinal study of volunteer search and rescue agents (aged 22–55 years) concluded that individuals pass through four stages during a serious rescue: preparation, performance, going over the edge and extending the edge. The extrapolation of these findings could be that extreme athletes are edgeworkers undergoing the same stages. In contrast, Celsi et al. [5] found that extreme sport participants did not feel they were pushing the edge of their control. Rather, they expressed a preference to stop the activity or postpone it for another day if they felt that the limits of their control were being overextended. Although edgework identifies key sociological factors that may drive participation, and emphasises positive participation outcomes, it may overlook additional relevant psychological motivations and benefits.

1.2.4 Additional Approaches

Other theories that have been presented to explain extreme sport participation include type 'T' personality theory and psychoanalysis. In the former theory, 'T' personalities search out risk, whereas 't' personalities avoid risk [46]. In this context, the big 'T' signifies thrills, and people with big 'T' personalities seek thrills, risks, arousal and novel sensations. One of the main distinctions in this theory is the recognition of both constructive (e.g. creativity, invention) and destructive (e.g. destruction, crime) outcomes of type 'T' personality. However, little research has been done on this theory, and as such, it remains an untested unidimensional theory.

Psychoanalytic theory has been used to explain participation in extreme sports through the *death wish* and other assumptions of pathological desires [2]. For example, Hunt [24] extrapolated findings from a study on a deep-sea diver experiences to explain participation in 'risk sports' in general. Hunt [24, 47–50] reasoned that pathological concerns in everyday life that manifest as aggressive fantasies, lack of power and concerns about masculinity and bisexuality might lead a person into dangerous sports: 'the more risky and violent the sport, the more likely do issues of bisexuality, masculinity, aggression, and sadomasochism appear to influence an individual's sport participation' [49]. Despite these conjectures, Hunt [49] concluded that individuals react differently to childhood patterns and that her findings might only apply to some individuals, rather than all extreme sport athletes. Interestingly, she also found connection amongst extreme sport participation, rich intelligence and the desire for creativity and meaning. The limitations of this research include: exclusive focus on men with no mention of female participants or motives and a focus on pathological explanations.

In summary, risk- or thrill-seeking explanations have considerable limitations in presenting a holistic psychological picture of extreme sport athletes. Perhaps as Farley [46] noted:

> too much energy is spent trying to pathologize those that are not like us. I sometimes think psychologists see too much pathology out there … To

> the contrary, these are people who are pushing the envelope and that's their life. They would not want the life of someone who never pushes the envelope. To them, that is an unlived life. [51]

1.3 Beyond Risk and Thrill

Milovanovic [52] suggested that risk-focused explanations of extreme sport participation were overly simplistic and based on naïve non-participant viewpoints, as opposed to the experiences of participants themselves. In addition, risk-focused accounts of participation are often driven by theories based on deficit models of behaviour. These theories may rely on prior judgements or assumptions that are unsupported by the participant reports [4, 5, 53–59].

For instance, Celsi et al. [5] cited numerous examples of well-respected extreme sportspeople who participated well within their personal capabilities; these participants preferred to defer their activity to a later date if they felt the limits of their control were being overextended. Pain and Pain [2] observed that extreme athletes expend considerable time and effort honing high-level skills, conducting extensive planning and developing a deep understanding of their particular activity. These athletes deliberately study all potential variables, such as the environment, their equipment and the weather.

Interestingly, statistical comparisons amongst the death rates of motorcyclists, BASE jumpers and climbers show that BASE jumping is far less likely to result in serious injury than motorcycle riding [6, 60]. Perhaps, as Storry [60] recognised, the tendency to focus on 'risk' or 'thrill' motivations misses the point entirely. Extreme sports are not necessarily synonymous with risk, and participation may not be focused on risk-taking. On the contrary, research suggests that extreme sport participants are careful, well trained, well prepared and self-aware and prefer to remain in control. This conclusion is supported by Pain and Pain:

> Despite the public's perception, extreme sports demand perpetual care, high degrees of training and preparation, and, above all, discipline and control. Most of those involved are well aware of their strengths and limitations in the face of clear dangers. Findings of extensive research in climbers suggest that the individuals do not want to put their lives in danger by going beyond personal capabilities. [2]

A myopic focus on the desire for risk also makes it difficult to explain why a person chooses skiing or BASE jumping above surfing or mountaineering. These are purposeful choices often made years in advance of participation [5]. If risk-taking were the sole aim of these activities, it is questionable whether participants would spend years preparing to ensure relative 'safety' before undertaking their chosen pursuit [61]. For instance, there are examples where participants have take approximately 6 years to plan one BASE jump [62] and 14 years to plan one expedition [63]. Therefore, it is likely that participants strictly motivated by risk or prone to impulsivity would opt for alternative, more immediately rewarding means of pursuing risk and experiencing thrills.

In summary, researchers following the traditional theory-driven perspectives on extreme sports have generally assumed that participation is motivated by risk and thrills. Participants are often portrayed as self-deceivers searching for thrills and uncertainty. However, evidence reveals that these assumptions may be largely inaccurate. The traditional risk focus may in fact be a function of our modern aversions to risk or obsessive desires to be liberated from risk. The notion of 'risk' has always been a part of life; it is only relatively recently that the lack of certainty and need to control our surroundings have been boxed as a construct and labelled as something deviant. The extreme sport experience might be a function of many factors that have been overlooked due to this societal aversion to risk. Furthermore, risk-focused explanations of extreme sports concentrate exclusively on potential negative outcomes. The problems with this approach are (1) literature reveals characteristics and statistics that do not fit with traditional assumptions of risk motivations [5, 6, 60]; (2) the focus on risk has largely obscured other aspects of the extreme sport experience [41, 55, 56, 59]; and (3) traditional theory-driven perspectives often do not match the lived experiences of participants [56, 59]. Thus, holistic investigations of extreme sport participation may lead to some more diverse theories and understandings of this phenomenon.

1.4 Towards Positive Psychological Explanations of Extreme Sport Participation

The following sections outline more positive psychological explanations of extreme sport participation that stem from an investigation of the lived experience of participants. In this section, we demonstrate, through reference to published literature and new research data, that the extreme sport experience has many positive psychological explanations that do not require a risk-focused presupposition.

1.4.1 Peak Experience and Flow

Peak experiences and flow have similar and overlapping characteristics [64]. Peak experiences focuses on the realisation of intense joy, whereas flow is an intrinsically rewarding experience characterised by optimal experience and complete immersion in the task at hand. Despite their differences, these two constructs describe positive subjective experiences and provide a basis for extreme sport motivation. Csikszentmihalyi [65, 66] described flow as an experience so enjoyable that people wanted to repeat it for its own sake, regardless of external rewards. Flow states have been documented in a wide range of activities including extreme sports, conducting surgery and flower arranging. For example, the 'deep flow' or 'deep play' of climbing is 'an outstanding example of a particular class of flow activities' [67]. Terms used to describe flow experiences include 'being in the zone' [68] and 'fun' [67, 69–71]. Early studies of flow in rock climbing illustrate a range of motivations and positive experiences aside from risk or thrill seeking (Table 1.1). Initial flow models have since been refined to include nine flow dimensions: challenge-skill balance, merging of action and awareness, clear goals, unambiguous feedback, concentration on the task at hand, paradox of control, loss of self-consciousness, transformation of time and autotelic experience [70].

Table 1.1 Deep-flow experiences in rock climbing in comparison to normative life experiences (Copyright © 1975 by Jossey-Bass Inc.) [66, 67]

Normative life	Rock climbing life
Informational noise: distraction and confusion of attention	One-pointedness of mind
Nebulosity of limits, demands, motivation, decisions, feedbacks	Clarity and manageability of limits, demands, decisions, feedbacks
Severing of action and awareness	Merging of action and awareness
Hidden, unpredictable dangers: unmanageable fears	Obvious danger subject to evaluation and control
Anxiety, worry, confusion	Happiness, health, vision
Slavery to the clock, life lived in spurts	Time out of time: timelessness
Carrot-and-stick preoccupation with exotelic, extrinsic material and social reward, orientation towards ends	Process orientation; concern for autotelic, intrinsic rewards; conquest of the useless
Dualism of mind and body	Integration of mind and body
Lack of self-understanding, false self-consciousness, wars between the selves	Understanding of the true self, self-integration
Miscommunication with others; masks, statuses and roles in an inegalitarian order; false independence or misplaced dependency	Direct and immediate communication with others in an egalitarian order, true and welcomed dependency on others
Confusion about man's place in nature or the universe, isolation from the natural order, destruction of the earth	Sense of man's place in the universe, oneness with nature, congruence of psychological and environmental ecology
Superficiality of concerns, thinness of meaning in the flatland	Dimension of depth 'up there'; encounter with ultimate concerns

Table 1.2 Maslow's 19 peak experience characteristics [74]

Characterisations	Meaning
Experience/object unification	Total harmony
Total attention	Complete absorption in the experience
Nature of the object in itself	Feeling of insignificance
Rich perception	Lost in the experience
Awe, reverence of the experience	The most blissful moment, ecstasy
Unity of the world	Feeling the world is unified
Abstract perception	Transcend the present situation
Fusion of dichotomies	The person and the experience merge
Feeling godlike	Fullest potential/total control
Nonclassifying perception	A new kind of viewing
Ego transcendence	They are the activity
Self-justifying moment	The experience as an end in itself
No consciousness of time and space	Lack of spatio-temporal consciousness
Experience is intrinsically perfect	Everything is perfect, beautiful, lasting
Awareness of the absolute	The ultimate truth is experienced
Effortlessness	No conscious deliberation in executing skills
Loss of fear	Momentary loss of psychological defences
Unique being of the individual	Experiences the totality of one's unique self
Fusion of the individual	Feeling integrated or together

Maslow [72] considered peak experiences to be almost mystical in nature and epitomised them as 'a "little death" and a rebirth in various senses' [72]. Panzarella (1980) [73] maintained that peak experiences were more likely to occur in people who are considered to be self-actualised. In a study with veteran skydivers, Lipscombe (1999) [74] found that all participants reported at least eight of Maslow's [72] 19 peak experience characteristics (Table 1.2). These eight characteristics were total attention, rich perception, awe or reverence of the experience, fusion of dichotomies, fusion of the individual, experience or object unification, ego transcendence and intrinsically perfect experience. Lipscombe [74] argued that as few as three of these original characteristics may be required for a peak experience to occur. These results suggest that veteran skydivers' peak experiences may not rely on perceptions of risk or thrill but rather result from feelings of 'acute well-being, peace, calm and stillness, detachment, uniqueness, freedom, floating, flying and weightlessness, ecstasy, being in the present, immersed in the moment, immortality, unity, altered perceptions of time and space, self-validation, and awareness of other'.

Research on extreme sport experiences mirrors many of the concepts identified in flow and peak experience research. For example, Brymer and Schweitzer [57, 58] found that extreme sport athletes described time slowing down and deep, meaningful experiences epitomised by feelings of freedom. Brymer and others [55, 75, 76] also describe how extreme sports change the way individuals experience the natural environment through feelings of connection and integration. Recent flow research further supports the notion that extreme sport participants are intrinsically motivated by flow dimensions and suggests that researchers should reconsider traditional characteristics of 'flow' amongst extreme and adventure athletes. Studies indicate that, rather than a singular state of flow, adventure participants may experience a range of flow states with varying felt arousal levels, perceived challenge and skill levels and phases, depending on their attentional focus and goals [77, 78]. Participants in these studies reported experiencing both *telic flow* (a serious, outcome-oriented state) and *paratelic flow* (a playful, process-oriented state). Although these flow states were equally enjoyable, they were described as qualitatively distinct experiences. For example, in situations of high challenge, such as those present for extreme sport activities, participants most often described *telic flow*. In this state, participants sought to lower their arousal levels and enjoyment resulted from goal attainment, rather than sensations of excitement or thrills. In contrast, *paratelic flow* represents a more traditional model of extreme sport participation wherein heightened challenge and high arousal are experienced as enjoyable and thrilling. In these studies, participants reported telic flow more frequently than paratelic flow, an indication that they were generally motivated by flow dimensions rather than sensation seeking or immediate excitement.

The theories of peak experience and flow appear to encompass much of the extreme sport experience. However, additional factors have emerged that may further expand our understanding of this phenomenon in the future. Extreme sport athletes describe characteristics that do not seem to clearly fit existing constructs. For example, Brymer (2009) [53] reported that participants experience lasting transformations. This longer-term effect contrasts with Maslow's definition of fleeting peak experiences [74, 79]. Participants also report expectations that flow or peak experiences will accompany extreme sports each time they are repeated. This finding also contrasts with Maslow's postulate that peak experiences are very rare, or once-in-a-lifetime, occurrences [72]. As such, the extreme sport experience might relate more to human experiences characterised as extraordinary and transcendent experiences.

Conclusion

In summary, extreme sport experiences appear to facilitate positive psychological experiences and lead to altered states of consciousness such as changes in perception of time and heighten sensory awareness. These findings contradict traditional theories of extreme sport participation. Recent literature suggests that extreme sport experiences are often extraordinary, transcendent and transforming. For extreme sport participants, the opportunity to transcend the everyday experience may provide more motivation and inspiration than experiencing short-term thrills through risk-taking.

References

1. American Sports Data. "Generation Y" drives increasingly popular "extreme" sports. Sector Analysis Report. http://www.americansportsdata.com/pr-extremeactionsports.asp. Accessed on Nov 2002.
2. Pain MT, Pain MA. Essay: risk taking in sport. Lancet. 2005;366(1):33–4.
3. Puchan H. Living 'extreme': adventure sports, media and commercialisation. J Commun Manag. 2004;9(2):171–8.
4. Brymer E. Extreme dude: a phenomenological exploration into the extreme sport experience. Wollongong: Doctoral Dissertation-University of Wollongong; 2005. Retrieved from http://ro.uow.edu.au/theses/379.
5. Celsi RL, Rose RL, Leigh TW. An exploration of high-risk leisure consumption through skydiving. J Consum Res. 1993;20:1–23.
6. Soreide K, Ellingsen C, Knutson V. How dangerous is BASE jumping? An analysis of adverse events in 20,850 jumps from the Kjerag Massif, Norway. J Trauma. 2007;62(5):1113–7.
7. Stookesberry B. New waterfall world record. Canoe & Kayak. 2009. http://canoekayak.com/whitewater/kayaking/new-waterfall-record/.
8. Warshaw M. Maverick's: the story of big-wave surfing. San Francisco: Chronicle Books; 2000.
9. Schneider M. Time at high altitude: experiencing time on the roof of the world. Time Soc. 2002;11(1):141–6.
10. Bennett G, Henson RK, Zhang J. Generation Y's perceptions of the action sports industry segment. J Sport Manage. 2003;17(2):95–115.
11. Davidson L. Tragedy in the adventure playground: media representations of mountaineering accidents in New Zealand. Leis Stud. 2008;27(1):3–19.
12. Pollay RW. Export "A" ads are extremely expert, eh? Tob Control. 2001;10:71–4.
13. Rinehart R. "Babes & Boards": opportunities in new millennium sport? J Sport Soc Issues. 2005;29:232–55.
14. Rinehart R. Emerging arriving sports: alternatives to formal sports. In: Coakle J, Dunning E, editors. Handbook of sports studies. London: Sage; 2000. p. 501–20.
15. Brymer E. Extreme sports: theorising participation – a challenge for phenomenology. Paper presented at the ORIC research symposium. University of Technology, Sydney; 2002:25.
16. Delle Fave A, Bassi M, Massimini F. Quality of experience and risk perception in high-altitude climbing. J Appl Sport Psychol. 2003;15:82–98.

17. Lambton D. Extreme sports flex their muscles. Allsport. 2000;49:19–22.
18. Olivier S. Moral dilemmas of participation in dangerous leisure activities. Leis Stud. 2006;25(1):95–109.
19. Pizam A, Reichel A, Uriely N. Sensation seeking and tourist behavior. J Hosp Leis Mark. 2002;9(3/4):17–33.
20. Self DR, Henry ED, Findley CS, Reilly E. Thrill seeking: the type T personality and extreme sports. Int J Sport Manage Mark. 2007;2(1–2):175–90.
21. Simon J. Taking risks: extreme sports and the embrace of risk in advanced liberal societies. In: Baker T, Simon J, editors. Embracing risk: the changing culture of insurance and responsibility. Chicago: University of Chicago Press; 2002. p. 177–208.
22. Rossi B, Cereatti L. The sensation seeking in mountain athletes as assessed by Zuckerman's sensation seeking scale. Int J Sport Psychol. 1993;24:417–31.
23. Zuckerman M. Are you a risk taker. Psychology Today. 2000:130.
24. Hunt JC. Divers' accounts of normal risk. Symb Interact. 1995;18(4):439–62.
25. Apter MJ. The dangerous edge: the psychology of excitement. New York: Free Press; 1992.
26. Kerr JH. Arousal-seeking in risk sport participants. Personal Individ Differ. 1991;12(6):613–6.
27. Lyng S, Young K. Risk-taking in sport: edgework and the reflexive community. In: Atkinson M, editor. Tribal play: subcultural journeys through sport. Bingley: Emerald; 2008. p. 83–109.
28. Zuckerman M. Sensation seeking: beyond the optimal level of arousal. Hillsdale: Erlbaum;1979;27:510.
29. Schroth ML. A comparison of sensation seeking among different groups of athletes and nonathletes. Personal Individ Differ. 1995;18(2):219–22.
30. Zuckerman M. Experience and desire: a new format for sensation seeking scales. J Behav Assessment. 1984;6(2):101–14.
31. Zuckerman M, Bone RN, Neary R, Mangelsdorff D, Brustman B. What is the sensation seeker? Personality trait and experience correlates of the sensation seeking scales. J Consult Clin Psychol. 1972;39(2):308–21.
32. Schrader MP, Wann DL. High-risk recreation: the relationship between participant characteristics and degree of involvement. J Sport Behav. 1999;22(3):426–31.
33. Zarevski P, Marusic I, Zolotic S, Bunjevac T, Vukosav Z. Contribution of Arnett's inventory of sensation seeking and Zuckerman's sensation seeking scale to the differentiation of athletes engaged in high and low risk sports. Personal Individ Differ. 1998;25:763–8.
34. Goma M. Personality profiles of subjects engaged in high physical risk sports. Personal Individ Differ. 1991;12(10):1087–93.
35. Slanger E, Rudestam KE. Motivation and disinhibition in high risk sports: sensation seeking and self-efficacy. J Res Pers. 1997;31(3):355–74.
36. Apter MJ. Motivational styles in everyday life: a guide to reversal theory. Washington, DC: American Psychological Association; 2001.
37. Frey KP. Reversal theory: basic concepts. In: Kerr JH, editor. Experiencing sport: reversal theory. New York: Wiley; 1999. p. 3–17.
38. Apter MJ. The experience of motivation: the theory of psychological reversals. London: Academic; 1982.
39. Apter MJ. Phenomenological frames and the paradoxes of experience. In: Kerr JH, Murgatroyd SJ, Apter MJ, editors. Advances in reversal theory. Amsterdam: Swets & Zeitlinger; 1993. p. 27–39.
40. Shoham A, Rose GM, Kahle LR. Practitioners of risky sports: a quantitative examination. J Bus Res. 2000;47(3):237–51.
41. Kerr JH, Houge Mackenzie S. Multiple motives for participating in adventure sports. Psychol Sport Exerc. 2012;13(5):649–57.
42. Lyng S. Sociology at the edge: social theory and voluntary risk taking. In: Lyng S, editor. Edgework: the sociology of risk-taking. Abingdon: Routledge; 2005. p. 17–49.
43. Lois J. Peaks and valleys: the gendered emotional culture of edgework. Gend Soc. 2001;15(3):381–406.
44. Lyng S. Edgework: a social psychological analysis of voluntary risk taking. AJS. 1995;4:851–86.
45. Stranger M. The aesthetics of risk. Int Rev Sociol Sport. 1999;34(3):265–76.
46. Farley F. The type-T personality. In: Lipsitt L, Mitnick L, editors. Self-regulatory behavior and risk taking: causes and consequences. Norwood: Ablex Publishers; 1991.
47. Hunt JC. Straightening out the bends. AquaCorps. 1993;5:16–23.
48. Hunt JC. The neutralisation of risk among deep scuba divers: Unpublished; 1995.
49. Hunt JC. Diving the wreck: risk and injury in sport scuba diving. Psychoanal Q. 1996;65:591–622.
50. Hunt JC. Why some of us don't mind being in deep water. Star Ledger. 1998;16.
51. Terwilliger C. Type 'T' personality. Denver Post. 1998;1:4–5.
52. Milovanovic D. Edgework: a subjective and structural model of negotiating boundaries. In: Lyng S, editor. Edgework: the sociology of risk-taking. Abingdon: Routledge; 2005. p. 83–109.
53. Brymer E. Extreme sports as a facilitator of ecocentricity and positive life changes. World Leis J. 2009;51(1):47–53.
54. Brymer E. Risk and extreme sports: a phenomenological perspective. Ann Leis Res. 2010;13(1–2):218–39.
55. Brymer E, Downey G, Gray T. Extreme sports as a precursor to environmental sustainability. J Sport Tour. 2009;14(2–3):1–12.
56. Brymer E, Oades LG. Extreme sports: a positive transformation in courage and humility. J Humanist Psychol. 2009;49(1):114–26.
57. Brymer E, Schweitzer R. Extreme sports are good for your health: a phenomenological understanding of fear and anxiety in extreme sports. J Health Psychol. 2012;18(4):477–87.

58. Brymer E, Schweitzer R. The search for freedom in extreme sports: a phenomenological exploration. Psychol Sport Exerc. 2013;14(6):865–73. doi:10.1016/j.psychsport.2013.07.004.
59. Willig CA. Phenomenological investigation of the experience of taking part in 'Extreme Sports'. J Health Psychol. 2008;13(5):690–702.
60. Storry T. The games outdoor adventurers play. In: Humberstone B, Brown H, Richards K, editors. Whose journeys? The outdoors and adventure as social and cultural phenomena. Penrith: The Institute for Outdoor Learning; 2003. p. 201–28.
61. Ogilvie BC. The sweet psychic jolt of danger. Psychol Today. 1974;8(5):88–94.
62. Swann H, Singleman G. Baseclimb 3 – the full story 2007. http://www.baseclimb.com/About_BASEClimb3.htm.
63. Muir J. Alone across Australia. Camberwell: Penguin Books Australia; 2003.
64. Privette G. Peak experience, peak performance, and flow: a comparative analysis of positive human experiences. J Pers Soc Psychol. 1983;45(6):1361–8.
65. Csikszentmihalyi M. The flow experience and its significance for human psychology. In: Csikszentmihalyi M, Csikszentmihalyi I, editors. Optimal experience: psychological studies of flow in consciousness. New York: Cambridge University Press; 1988. p. 15–35.
66. Csikszentmihalyi M. Beyond boredom and anxiety: experiencing flow in work and play (25th Anniversary Edition ed.) San Francisco: Jossey-Bass; 2000.
67. Csikszentmihalyi M. Beyond boredom and anxiety. San Francisco: Jossey-Bass; 1975. p. 74–97.
68. Young J, Pain M. The zone an empirical study. Online J Sport Psychol. 1999;1(3):1–8.
69. Jackson SA. Factors influencing the occurrence of flow states in elite athletes. J Appl Sport Psychol. 1995;7:138–66.
70. Jackson SA. Toward a conceptual understanding of the flow experience in elite athletes. Res Q Exerc Sport. 1996;67(1):76–90.
71. Kimiecik JC, Harris AT. What is enjoyment: a conceptual/definitional analysis with implications for sport and exercise psychology. J Sport Exerc Psychol. 1996;18(3):247–63.
72. Maslow AH. Religions, values and peak-experiences. Harmondsworth: Penguin; 1977. p. 15.
73. Panzarella R. The phenomenology of aesthetic peak experiences. J Humanist Psychol. 1980;20(1):69–85.
74. Lipscombe N. The relevance of the peak experience to continued skydiving participation: a qualitative approach to assessing motivations. Leis Stud. 1999;18:267–88.
75. Brymer E, Gray T. Dancing with nature: rhythm and harmony in extreme sport participation. Adventure Educ Outdoor Learn. 2010;9(2):135–49.
76. Brymer E, Gray T. Developing an intimate "relationship" with nature through extreme sports participation. Loisir. 2010;34(4):361–74.
77. Houge Mackenzie S, Hodge K, Boyes M. Expanding the flow model in adventure activities: a reversal theory perspective. J Leis Res. 2011;43(4):519–44.
78. Houge Mackenzie S, Hodge K, Boyes M. The multiphasic and dynamic nature of flow in adventure experiences. J Leis Res. 2013;45(2):214–32.
79. Ravizza K. Peak experiences in sport. J Humanist Psychol. 1977;17:35–40.

2 Nutrition for Extreme Sports

Mayur K. Ranchordas, Sean Hudson, and Steve W. Thompson

2.1 Introduction

It has been well established that sound nutrition can accelerate recovery, enhance adaptations to training and improve performance. Competing in extreme sports places stress on the body, and conducting activities in extreme environments can exacerbate the physiological stress on the competitor. Fortunately, scientific research in this area is growing, and we now have a range of nutritional strategies that can help the athlete competing in extreme sports in various ways.

The physiological and metabolic requirements of different extreme sports vary greatly; thus providing specific nutritional recommendations is problematic. For instance, certain extreme sports such as cliff diving and climbing have very different nutritional needs compared to ultra-endurance long-distance events such as adventure racing, mountaineering and ultra-distance running. Nevertheless, the aim of this chapter is to provide both generic nutritional guidelines and specific recommendations for special circumstances.

2.2 General Nutritional Recommendations

2.2.1 Energy

Optimal dietary intake is essential for successful performance. Macronutrients consist of carbohydrates, proteins and fats and contribute to the majority of nutrients ingested. The manipulation of these both in terms of amounts and timing can provide athletes with a platform to aid performance dependent on the type of sport. Energy consumption must equal energy expenditure in order to achieve energy balance if the desired goal is weight maintenance. A negative or positive energy balance might be advantageous in certain situations where weight loss or muscle hypertrophy is required. General daily energy intake requirements are lower for females (1600–3700 kcal) than males (2900–5900 kcal); however this may vary due to athlete situation.

2.2.2 Carbohydrate

Carbohydrate (CHO) has four main roles in the body. The first is to act as a main energy source during high-intensity exercise in which glycogen (the stored form of carbohydrate) is broken down into glucose (glycogenolysis). Glucose is then used to create ATP through the process of glycolysis (oxidised to form water and carbon dioxide) [1]. CHO also helps to preserve important

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tissue proteins that are essential for muscular maintenance, repair and growth, provide an uninterrupted supply of fuel to the central nervous system as the brain metabolises blood glucose [2] and act as a metabolic primer for fat oxidation. The readily available carbohydrate sources are fairly limited (i.e. 1500–2000 kcal) and become a restrictive factor in the performance of prolonged sessions (>90 min) of submaximal or intermittent high-intensity exercise [2]. Thus adequate intake of carbohydrates prior, during and after exercise is essential for extreme sports lasting longer than 90 min. It should be noted that carbohydrate guidelines will differ depending on intensities and duration of activity undertaken.

2.2.2.1 Intensity

As intensity increases, so does the release of glucose from the liver to the active muscles. Stimulation in muscle glycogen utilisation also occurs as the energy increases. This can be determined via performing gas analysis and referring to the respiratory exchange ratio. If the RER rises above 1.0, then CHO becomes the primary source of energy production. Therefore, the higher the intensity, the more CHO will be needed to maintain that desired workload. Thus the extreme sports that have short sharp bursts will have a greater reliance upon carbohydrate for fuel.

2.2.2.2 Duration

As exercise duration increases, muscle glycogen decreases, causing fat catabolism to begin to furnish an increasing percentage of total energy. Therefore, a greater amount of CHO may be required prior to exercise if competing for long durations. Also, simple CHO such as glucose can be ingested during exercise to maintain supply of glycogen to the muscles. The type and timing of CHO are also very important. More specifically, CHO can be determined by their complexity (mono-, di- or polysaccharides) and by their glycaemic index (GI). Despite a lot of conflicting research, it is thought that lower GI foods are more advantageous prior to exercise as they lead to an increase in free fatty acids, better maintenance and slower release of plasma glycogen, resulting in more sustained carbohydrate availability during exercise [3]. It is also agreed that during and directly after exercise, high GI and simple CHOs are advantageous (glucose and sucrose) as they are broken down quicker via glycolysis and promote faster muscle glycogen recovery [2, 4].

The American College of Sports Medicine (ACSM) [5] recommends 6–10 g/kg body weight of CHO per day (ACSM, 2009). However, this may fluctuate dependent on the sport undertaken as specified in Table 2.1.

2.2.3 Protein

Protein (PRO) is made up of a combination of amino acids (AA). Some PRO can be synthesised within the body such as alanine, serine and

Table 2.1 CHO guidelines for extreme sports

Intensity/duration	Recommended CHO intake	Extreme sports
Low to moderate intensity and duration (<1 h)	5–7 g/kg/day	BMX Rock climbing Snowboarding/skiing Windsurfing Surfing
Endurance athletes (1–3 h of moderate to high intensity) Extreme conditions (3+ h of moderate to high intensity)	7–10 g/kg/day 10–12+ g/kg/day	Mountaineering Ice climbing Cross-country skiing Ironman triathlons
Pre-exercise meal	1–4 g/kg 1–4 h prior	
During moderate- to high-intensity exercise (>1 h)	0.5–1.0 g/kg/h	
Rapid postexercise recovery	1 g/kg immediately after exercise and repeated 2 h later	

Adapted from Burke et al. [6]

glutamic acid. However, there are many essential AA that we are unable to synthesise such as leucine, lysine and tryptophan. Therefore, it is important that adequate ingestion of protein from the daily diet is undertaken to maintain protein synthesis and adequate recovery.

PRO is used primarily to promote muscle fibre repair, regeneration and growth [7]. They can however also be utilised as an energy source if CHO and fat sources have reduced significantly. For most sports, this is not a desired outcome as it may lead to a decrease in AA available for recovery and regeneration [8]. Dependent on the discipline of extreme sport, the recommended daily intake and intake for recovery differ greatly. The ACSM [5] have recommended 1.2–1.7 g/kg/day and that this is done via dietary intake. For endurance athletes, 1.7 g/kg may not be needed if adequate fuel is ingested through CHO and fat. But for any sport that requires strength and power (e.g. BMX, snowboard freestyle or free running), more than 1.7 g/kg/day could be advantageous [5]. However, it has been suggested that there is no harm in ingesting more protein than this. For example, for some sports that require large energy intakes (~6400 kcal), as much as 2.5–3.2 g/kg of PRO may be necessary [7].

In order to utilise the dietary requirements, again, the timing of ingestion of protein is essential. Studies have shown that ingestion of protein immediately before exercise promotes a greater net protein balance than ingestion postexercise following resistance exercise (providing adequate CHO has been ingested) [5, 9]. It has also been reported that net protein uptake is increased when a combination of PRO and CHO is ingested oppose to either of them on their own [7]. Protein ingested after training is still advantageous and should be in a simple form such as whey as it is rapidly digestible.

2.2.4 Fat

Fat (lipids) is a necessary component of a normal diet for any athlete. Large amounts of fat can be stored in adipose tissue and thus can be readily available for prolonged exercise. Lipids also protect vital organs such as the heart, brain, liver and kidneys. They are an essential source of fat-soluble vitamins such as A, D, E and K and are important constituents of cell membranes. Cholesterol, which is a type of lipid, is a precursor for important hormones such as testosterone.

In accordance with the ACSM [5] guideline, fat consumption should range from 20 to 35 % of total energy intake across all intensities and durations. This should include approximately 10 % saturated, 10 % polyunsaturated and 10 % monounsaturated as well as including sources of essential fatty acids. Saturated fats should be avoided. For certain extreme sports such as mountaineering and extreme expedition-type events where competitors must carry their own food supplies, foods high in fat may be advantageous as they provide 9 kcal/g as opposed to carbohydrate and protein which provide 4 kcal/g. In these situations, where large energy expenditure is prevalent, foods high in fat can help maintain energy balance to an extent.

2.3 Weight Management

The principles of weight management remain the same regardless of the sport. Therefore this section will focus on general methods for weight gain or weight loss. Weight change is best done during the off-season or a period outside of competition to prevent any potential adverse effects on performance. For extreme sports such as rock climbing and ultra-endurance sports, a high power to weight ratio is desirable so competitors may want to manipulate body composition. Similarly, for other sports such as BMX, canoeing and white-water rafting, competitors may want to increase muscle mass and reduce body fat.

2.3.1 Weight Gain

Weight gain through increasing skeletal muscle mass (hypertrophy) is often advantageous in many sporting contexts and activities. To increase weight, an athlete must achieve a positive energy balance with muscle hypertrophy only occurring when muscle protein synthesis exceeds the rate of protein breakdown for a prolonged period of time [10]. The two principal determinants of skeletal muscle protein synthesis in adults are physical activity and nutrient availability [11].

Utilising protein ingestion with physical activity, particularly resistance exercise, promotes an optimal anabolic environment in the skeletal muscle compared to either stimulus alone [12]. The addition of protein ingestion following a bout of resistance exercise has repeatedly been shown to augment the stimulation of muscle protein synthesis, which over a period of resistance training with increased protein consumption can lead to muscular hypertrophy. The anabolic effects of nutrition are driven by the transfer and incorporation of amino acids captured from dietary protein sources into skeletal muscle proteins. The amino acid leucine has been highlighted to be particularly important in stimulating protein synthesis and appears to have a controlling influence over the activation of protein synthesis [13]. As such, rapidly digested leucine-rich proteins such as whey, in conjunction with resistance exercise, are advised for individuals wishing to increase muscle mass. In terms of protein quantity, 20–25 g of high-quality protein with at least 8–10 g of essential amino acids [14] has been shown to maximally potentiate exercise-induced rates of muscle protein synthesis in healthy young adults [15]. In total, athletes are recommended to consume ~1.3–1.8 $g.kg^{-1}.d^{-1}$, consumed as four meals while attempting to gain weight through increasing muscle mass [16]. It should be noted that these recommendations are dependent on training status and more protein should be consumed during periods of high-frequency/high-intensity training.

2.3.2 Weight Loss

Weight loss is not an uncommon goal for athletes and is often motivated by factors relating to performance issues. This usually involves weight loss either to enhance performance or for aesthetic reasons. Excess fat is often detrimental to performance of physical activities requiring the transfer of body mass either vertically (such as in jumping) or horizontally (such as in running). This is because it adds mass to the body without providing any additional capacity to produce force. Excess fat can also be detrimental to performance through increasing the metabolic cost of physical activity that requires movement of the total body mass.

Weight loss can occur when a negative energy balance is created. Thus, weight loss can be achieved by restricting energy intake, increasing the volume/intensity of training or, most often, a combination of both these strategies. It is important for athletes and coaches to recognise that with extreme energy restrictions, losses of both muscle and fat mass may adversely influence an athlete's performance [17]. Therefore, in most cases, it is important for an athlete to preserve their fat-free mass during periods of weight loss. There is a growing body of evidence suggesting that higher protein intakes during energy restriction can enhance the retention of fat-free mass [18, 19]. A reduction in dietary fat and carbohydrate may allow athletes to achieve higher protein intakes without the excessive restriction of a particular macronutrient. Current recommendations advise athletes aiming to achieve weight loss without losing fat-free mass to combine a moderate energy deficit (~500 $kcal.d^{-1}$) with the consumption of between ~1.8 and 2.0 $g.kg^{-1}.d^{-1}$ of protein in conjunction with performing resistance exercise [14].

2.4 Nutritional Issues and Challenges

2.4.1 Travel

It is not uncommon that extreme sports athletes may be frequent travellers due to the nature of their sport and competition; thus they may face frequent trips that may involve long travel times that can cause fatigue. Having access to nutritious balanced meals and adequate fluid can be challenging; however, ample pre-planning meal, snack and fluid arrangements can

Table 2.2 Nutritional strategies for travel

Issue	Detail	Strategy
Infection and illness	Travelling poses the risk of infection and gastrointestinal disturbance when travelling (more so if travelling abroad)	Using antibacterial hand gels and washing hands often can minimise some risk. In addition the use of probiotics can also be useful in some instances
Catering	Different hotels and kitchens have their own way of preparing meals that may be very different to expectations	Communication with menu plans and possibly recipes and specific snack items may be useful
Food and water hygiene	In some countries it is ill advised to drink tap water, and foods such as fruit, vegetables, salads and ice cubes could pose a risk	Stick to drinking sealed bottled water and avoid swallowing water when brushing teeth; showering and ensuring food is washed with clean water that is not contaminated
Eating on the move	Travel poses uncertain issues such as delay and availability of food on the move; therefore the team should ensure that snacks and meals are pre-planned	Communication with travel companies, hotels and pre-packing food items are important as problems such as delays can pose a problem

Adapted from Ranchordas et al. [21]

enhance an athlete's dietary preparation when travelling [20]). Table 2.2 provides a practical summary of key dietary strategies that can help support teams cope with challenging travel demands.

2.5 Fluid and Electrolyte Requirements

2.5.1 Sweat Rates and Electrolytes

Exercise is associated with high rates of metabolic heat production, eliciting high rates of sweat secretion in order to attenuate the rise in body temperature that would otherwise occur. If exercise is prolonged, this leads to progressive hypohydration and a loss of electrolytes, particularly in hot environments where sweat rates may exceed 2 l/h [22].

Significant hypohydration can occur during many types of exercise activity and poses a challenge to both an individual's performance and health. Hypohydration can have a negative impact on exercise outcomes through impairing thermoregulation and performance of prolonged aerobic exercise [23], cognitive function [24] and gastric emptying and comfort [25]. These performance impairments can be detected when fluid losses are as low as 1.8 % of body mass [22]. A body mass loss of more than 4 % during exercise may lead to heat exhaustion and heat illness [22]. Even in winter sports environments, where sweat rates are expected to be lower, fluid loss can be significant [26]. Nordic skiers competing in 15–30-km races can typically lose 2–3 % of body mass, and collegiate cross-country skiers lost 1.8 % of body mass after 90 min of ski training [27]. Thus, strategies to minimise the degree of hypohydration should be undertaken before, during (if possible) and in recovery from exercise activities.

2.5.2 Measuring Hydration and Electrolyte Status

Sweat rates and electrolyte losses can vary widely amongst different individuals and between different activities under the same environmental conditions. Therefore, it is difficult to accurately prescribe fluid and electrolyte intakes without knowledge of individual sweat rates under the specific environmental conditions. Hydration status can be monitored by employing simple urine and body mass measurements. Changes in body mass can reflect sweat losses during exercise and can be used to calculate individual fluid replacement needs for specific exercise activities and environmental conditions. Urine osmolality also provides a clear indication of hydration status and can be measured quickly and simply using a portable osmometer. A urine osmolality of 100–300 mOsmol/kg indicates that an individual is well hydrated. Values of over 900 mOsmol/kg indicate that an individual is relatively dehydrated. Portable urine osmometers can be useful to assess hydration status in the field as they are small, reliable and convenient and thus can be a good tool to monitor hydration status objectively.

Accurately measuring electrolyte losses is a more challenging, as the composition of sweat is difficult to measure and the methods such as sweat patch testing have poor reliability. Electrolyte losses vary greatly between individuals but also vary with changing sweat rates over time [28]. The major electrolytes lost in sweat are sodium and chloride. These are the major ions of the extracellular space; therefore, the replacement of these ions, especially sodium, should be a priority. The perception of thirst as the signal to drink is unreliable. This is because a considerable degree of dehydration, sufficient enough to impair athletic performance, can occur before the desire to drink is evident [29]. The sensation of thirst results increases the secretion of the antidiuretic hormone from the posterior pituitary gland, which acts on the kidneys to reduce urine excretion. However, thirst is quickly alleviated through drinking fluid before a significant amount of fluid is absorbed in the gut [22]. Thus, the use of thirst alone should not be used as indicator of fluid balance.

2.5.3 Constituents of Fluid Ingested

Electrolytes play a key role in promoting postexercise rehydration. This was first highlighted by Costill and Sparks [30], who showed that the ingestion of a glucose-electrolyte solution after a relatively severe degree of hypohydration (4 % of the pre-exercise body mass) resulted in a greater restoration of plasma volume than water alone. A higher urine output was also observed in the water trial. The ingestion of drinks containing sodium following exercise promotes rapid fluid absorption in the small intestine, allows the plasma sodium concentration to remain elevated during rehydration and helps maintain thirst while delaying the stimulation of urine production. Drinks containing multiple transportable carbohydrates such as glucose and fructose can also aid hydration through enhancing gastric emptying rates, improving the delivery of fluid consumption compared to a single carbohydrate drink (this is covered in more detail in the carbohydrate supplements section) [31]. The addition of carbohydrate can also make the drink more palatable, aiding the rehydration process.

Gonzales-Alonso et al. [32] confirmed that a dilute carbohydrate-electrolyte solution (60 g/l carbohydrate, 20 mmol.l^{-1} Na+, 3 mmol.l^{-1} K+) was more effective in promoting postexercise rehydration than either plain water or a low-electrolyte diet cola. The difference between the drinks was primarily the volume of urine produced. As previously mentioned, individual sodium content of sweat varies widely, and no single formulation will meet requirements for all individuals in all situations. The upper end of the normal range for sodium concentration (80 mmol.l^{-1}), however, is similar to the sodium concentration of many commercially produced oral rehydration solutions intended for use in the treatment of diarrhoea-induced dehydration. In contrast, the sodium content of most sports drinks is in the range of 10–30 mmol.l^{-1}. Most commonly consumed soft drinks contain virtually no sodium, and these drinks are, therefore, unsuitable for rehydration. The problem with high sodium concentrations is that this may exert a negative effect on taste, resulting in reduced consumption. Therefore, it is important that a balance between electrolyte content and palatability is achieved.

2.5.3.1 Before Exercise

Beginning exercise in a hypohydrated state can have a negative impact on performance of high-intensity [33] and endurance exercise [34]. Thus, the main goal of fluid intake before exercise is to begin in a euhydrated state with normal plasma electrolyte levels. This can be achieved through consuming a balanced diet and drinking adequate fluid during a period 24 h before exercise event. Consuming a further 500 ml of fluid around 2 h before exercise helps promote adequate hydration and allow time for secretion of excess ingested water [5]. However, if an individual has suffered from substantial fluid loss and only has a short recovery period before a subsequent bout of exercise, then an aggressive prehydration strategy may be merited to establish euhydration.

Attempting to hyperhydrate before exercise will greatly increase the risk of having to void during competition and provides no clear physiological or performance advantage over euhydration [35, 36]. In addition, hyperhydration can substantially dilute and lower plasma sodium [37, 38] before starting exercise and therefore increase the risk of dilutional hyponatraemia, especially if fluids are aggressively replaced during exercise [39].

2.5.3.2 During Exercise

Extreme sports vary in nature and some in some sports; there may not be an opportunity to take on some fluids during exercise, whereas in other sports this may not be a problem. Nevertheless, if fluid intake during exercise is possible, then the main goal is to prevent excessive dehydration (>1.8 % body mass loss from fluid loss) and excessive changes in electrolyte balance that could impair performance.

During exercise, especially in a hot environment, dehydration can only be avoided by matching sweat loss with fluid consumption. However, sweat rates during strenuous exercise in the heat can be as high as 2–3 l/h, and a volume of ingested fluid of more than about 1 l feels uncomfortable in the stomach for most people when exercising. Therefore, achieving fluid intakes that match sweat losses during exercise is often not practical. In these situations, it may be necessary to rehydrate after exercise, especially if there is a second bout of exercise later that day or the day after (e.g. for sports such as adventure racing and expedition-type activities).

Fluid intake during strenuous exercise lasting less than 30 min in duration offers no advantage. Gastric emptying is inhibited at high work rates, and insignificant amounts of fluid are absorbed during exercise of short duration. For most individuals exercising for 30–60 min in moderate ambient conditions, an appropriate drink is cool water. For exercise lasting more than 1 h or exercise in hot and humid conditions, consumption of a drink containing carbohydrates and electrolytes is warranted. Fluid ingestion during prolonged exercise provides an opportunity for exogenous fuel consumption as well as helping to maintain plasma volume and preventing dehydration. The replacement of electrolytes lost in sweat can normally wait until the postexercise recovery period as stated previously. Individuals should become accustomed to consuming fluid at regular intervals (with or without thirst) during training sessions so that they do not experience discomfort during competition.

2.5.3.3 Postexercise

After exercise the main goal of fluid intake is to fully replace fluid electrolytes lost during exercise and return to a euhydrated state. As previously mentioned, this is particularly important when exercise is prolonged and takes place in a hot environment or when consuming fluid during exercise is not possible.

Even when fluids are available during longer exercise periods, the volume ingested is rarely sufficient to match the rate of sweat loss, and some degree of fluid deficit usually accompanies exercise. Replacement of these losses must be achieved in the recovery period after exercise ends before the next bout of exercise is undertaken.

Fluid intake also comes from food consumption. Some foods, especially plant material, have high water content. In fact, water in food makes a major contribution to total body fluid intake. Water is also produced internally (metabolic water) from the catabolism of water, fat and protein. For example, in the complete oxidation of one molecule of glucose, six molecules of carbon dioxide and six molecules of water are produced. Therefore, consuming food with fluid following exercise is recommended to aid rehydration while also providing essential electrolyte replenishment.

On the completion of exercise, individuals are encouraged to consume a volume of fluid equivalent to 150 % of sweat loss (i.e. 1.5 l of fluid consumed during recovery from exercise for every kilogram of body mass loss during exercise) within 6 h after exercise. This is to account for continued fluid loss from sweat and urine following the cessation of exercise.

2.6 Special Nutrition Considerations for Extreme Sports: Practical Recommendations

Individuals should attempt to begin all exercise sessions in a euhydrated state. Taking current recommendations into consideration [5, 40], individuals participating in extreme sports where significant sweat losses have occurred should ingest a volume of fluid substantially greater than the volume of sweat lost. This should equate to around 150 % of sweat loss over a 6-h period in order to account for continued sweat and urine losses following the cessation of exercise. This clearly requires knowledge of sweat loss, and a reasonable estimate can be obtained from changes in body mass. An effective rehydration drink intended for consumption after exercise should be both effective and palatable.

For optimal hydration during prolonged exercise, particularly in hot and humid environments, the addition of sodium (10–30 mmol.l^{-1}) in conjunction with multiple carbohydrates can aid fluid uptake, provide an exogenous fuel source and prevent excessive hypohydration. The ideal drink for fluid replacement is one that tastes good to the individual, does not cause gastrointestinal discomfort when consumed in large volumes, promotes gastric emptying and fluid absorption to help maintain the extracellular volume and provides some energy to the muscle in the form of carbohydrate.

2.6.1 Nutritional Strategies for Cooling

The rise in core body temperature observed when exercise is performed in hot environmental conditions is associated with reduced motor output during self-paced exercise [41, 42], as well as the termination of exercise during time to exhaustion protocols [43, 44]. The central nervous system is thought to reduce motor output following elevations in core temperature and terminate exercise once critically high internal temperatures are attained, in an attempt to limit the development of catastrophic heat illness [45].

The subjective perception of effort is an important consideration. If the exercise feels hard, the duration will often be cut short and adherence is likely to be poor. It is well recognised that the subjective rating of perceived exertion is higher when exercise is performed in warm environments than in cool environments [46] and is also increased by even moderate levels of hypohydration.

Total body water can have a critical influence on thermoregulation and exercise performance in the heat. Total body water usually remains relatively constant [47]; however, physical exercise and heat exposure will increase water flux to support thermoregulation [48]. In a hot environment, sweat evaporation is the primary avenue for dissipating body heat absorbed from the environment or produced by the exercising muscle. Therefore, the most notable effect of exercise in a hot climate is increased fluid loss.

Hypohydration increases heat storage by reducing skin blood flow and sweating rate responses for a given core temperature. Hypohydration lowers both intracellular and extracellular fluid volumes. It also results in plasma hypertonicity, with the potential effect being greater in warm environments.

Pre-exercise cooling is a strategy for improving prolonged exercise performance in the heat. This is based on evidence that reducing initial core temperature allows for a greater heat storage capacity during exercise, in turn prolonging the onset of hyperthermia-induced fatigue [49]. The ingestion of cold fluid or ice slurries has been suggested as nutritional strategies that could be used for internal cooling. Indeed, ingesting cold water (4 °C) versus warm water (37 °C) before and during exercise in hot environments prolonged cycling time to exhaustion by 23 ± 6 % [50]. The pre-exercise ingestion of ice slurry (−1 °C) has been shown to be even more effective compared to cold water (4 °C) at lowering rectal temperature and extended the ensuing running time to exhaustion by 19 ± 6 % [51]. The ingestion of substantial volumes (6.5–7.5 g.kg^{-1} body mass) of ice slurry in 30 min prior to exercise has repeatedly been shown to improve endurance capacity and performance during exercise [51–54] and appears to be the most effective nutritional strategy for cooling.

2.7 Supplements and Ergogenic Aids

The use of sports foods and dietary supplements amongst athletes is widespread; however, many products are not effective and lack evidence for improving soccer performance. Moreover, many supplements have been found to be contaminated and could increase the risk of a positive doping test; thus athletes who are subjected to anti-doping testing should ensure that dietary supplements are batch tested for contamination before use. This section provides an overview of certain supplements that may be beneficial for extreme sports.

2.7.1 Creatine

Creatine supplementation increases intramuscular phosphocreatine stores and appears to enhance performance in activities that primarily involve repeated short bouts of high-intensity exercise that require energy from the ATP-PC energy system. Therefore, the rationale for using creatine supplementation to enhance performance in extreme sports such as downhill mountain biking, skateboarding, BMX and other extreme activities with short sharp bursts has merit considering that these activities consist of movements that predominately use the ATP-PC energy system over prolonged durations. The majority of the early research that has examined the effectiveness of creatine supplementation suggests using a loading phase of 5 g of creatine 4 times per day for the initial 5 days followed by a maintenance dose of 5 g/day to maximise phosphocreatine stores and enhance performance [55]. Creatine loading may not be necessary if quick loading is not essential, and in this case a dose of 5 g either once daily or twice daily is adequate. Creatine seems to be more effective when taken with high GI carbohydrates as the increase in blood glucose and subsequently insulin plays a role in the absorption of creatine within the muscle so competitors are encouraged to take the 5-g dose of creatine with approximately 40 g of high GI carbohydrate [56].

2.7.2 Beta-Alanine

Supplementing the diet with beta-alanine may have an ergogenic effect on high-intensity exercise, particularly exercise capacity, in activities lasting between 1 and 4 min [57, 58]. Thus extreme sports that fall within this range such as skateboarding, BMX, downhill mountain biking and surfing may benefit from beta-alanine supplementation. The rate of carnosine synthesis in the human skeletal muscle is limited by the availability of beta-alanine from the diet [59]. Although several potential roles have been ascribed to carnosine in the skeletal muscle, its main role has been identified as an intramuscular pH buffer due to its molecular structure [60, 61].

High-intensity exercise can lead to an accumulation of hydrogen ions (H+) in the skeletal muscle, causing a reduction in the intramuscular pH. Under normal resting conditions, intramuscular pH is around 7.0. However, during high-intensity exercise, muscle pH may fall to as low as 6.0 [62]. This can result in reduced muscle function and force generation, contributing to fatigue.

Carnosine molecules contain an imidazole ring that allows it to lend itself as an intracellular buffer through directly accepting and buffering H+ ions [63]. With a pKa of 6.83 and its high concentration in the muscle, specifically fast-twitch fibres [59], carnosine can act as a powerful immediate H+ buffering agent [64]. A higher muscle buffer value may benefit prolonged high-intensity exercise performance by allowing for a higher accumulation of H+ in the muscle before reaching a limiting muscle pH.

Supplementing the diet with 6.4 g of β-alanine per day for 4 weeks has been shown to increase carnosine concentrations in the skeletal muscle by ~60 % [60] and by ~80 % when supplementing for 10 weeks with the same quantity [58]. Stellingwerff and colleagues [65] suggested that for a desired increase (~50 %) in muscle carnosine, a total of ~230 g of beta-alanine must be taken within a daily consumption range of 1.6–6.4 $g.d^{-1}$. Higher doses are not advised due to the potential for symptoms of paresthesia [59]. Additionally, once muscle carnosine is augmented, the washout period is very slow at ~2 % per week [65].

2.7.3 Dietary Nitrates

Over recent years, the use of dietary nitrates has become popular in sport, and there are now supplements such as concentrated beetroot shots, nitrate-containing gels and bars available that are purported to enhance performance. Various studies have found that approximately 8.4 mmol of dietary nitrate can improve tolerance to endurance exercise, reduce the oxygen cost of exercise and increase time to exhaustion which can be beneficial for extreme sports that have a large endurance exercise component such as ultra-endurance exercise [66, 67]. The type of supplement used in these studies has been mainly concentrated beetroot shots which are commercially available. One study has investigated the effects of dietary nitrate supplementation in hypoxic conditions. Kelly and co-workers [68] investigated the effects of 140 ml of concentrated beetroot juice that contained approximately 8.4 mmol of nitrate and a placebo ingested for 3 days prior to a cycling performance test in 12 healthy participants during normoxia (20.9 % O2) and hypoxia (13.1 % O2). It was found that in hypoxia, nitrate supplementation enhanced VO2 kinetics during moderate-intensity exercise and improved severe-intensity exercise tolerance. These findings suggest that nitrate supplementation may have important benefits for individuals exercising in conditions at high altitude; thus competitors in extreme sports such as high-altitude climbing and expedition-type events should consider the use of nitrate supplementation.

2.7.4 Caffeine

Caffeine has been studied extensively over the last two decades, and numerous studies have demonstrated that caffeine can enhance endurance performance [69, 70]. The use of caffeine for performance has several benefits including the mobilisation of fatty acids to enhance fuel use, changes to muscle contractility, stimulation of the central nervous system and stimulation of the release and activity of adrenaline [71].

For extreme sports that are characterised by very long distances where athletes often choose to go without sleep for a period of greater than 24 h while competing in events such as expeditions, caffeine can be used by competitors to help them stay awake and enhance performance. When taken in low to moderate doses (3–6 $mg.kg^{-1}$), caffeine is effective for enhancing endurance performance [69, 70], and it has been demonstrated that caffeine can enhance vigilance during bouts of extended exhaustive exercise, as well as periods of sustained sleep deprivation [72–74]. It should be noted that the scientific literature does not support the theory of caffeine-induced diuresis during exercise or detrimental effects on fluid balance that would negatively affect performance; therefore, caffeine use should be considered by extreme sports athletes.

2.7.5 Carbohydrate Supplements

Sports drinks, gels and bars are a convenient and portable source of carbohydrate that can be consumed during exercise. The carbohydrate content in these products is typically derived from glucose and dextrose, and numerous studies have found that sports drinks, gels and bars can prolong endurance performance [75–77]. More recently, however, there have been developments regarding the type of carbohydrate and its effects on endurance performance. Currell and

Jeukendrup [78] found that sports drinks containing glucose and fructose in a ratio of 2:1 led to an 8 % improvement in cycling time-trial performance compared to ingestion of glucose alone. These findings have since been replicated and furthered in several other studies [31, 79, 80] which have demonstrated that sports drinks and gels containing multiple transportable carbohydrates (i.e. glucose and fructose), when ingested at high rates, can be beneficial during endurance sports in which the duration of exercise is 3 h or more. For extreme sports lasting longer than 2 h, it may be beneficial for competitors to take on sports drinks, gels and bars that contain multiple transportable carbohydrates in the form of glucose and fructose. Supplements that provide 60–90 $g.h^{-1}$ of multiple transportable carbohydrates should be consumed during prolonged exercise. Competitors should practise feeding strategies during training to ensure that these carbohydrate doses are well tolerated. Moreover, due to individual preferences, certain competitors may prefer taking carbohydrate supplements in the form of a gel or bar as opposed to a drink.

2.7.6 Contamination of Supplements

The sports food and dietary supplement market is saturated with various purportedly ergogenic aids to enhance strength, speed, endurance and recovery. However, few are substantiated by convincing scientific evidence. Some supplements reviewed in this chapter such as carbohydrates and caffeine can enhance performance in extreme sports. However, it should be recognised that nutritional supplements can be a source of contamination and, hence, a positive doping test. Various studies have shown that commercially available dietary supplements and ergogenic aids available over the Internet or over the counter are contaminated with substances banned on the WADA list of prohibited substances [81, 82]. It is important that extreme sports athletes take supplements that are evidence based and free from contamination; thus it is a good practice to seek sports nutrition advice from a qualified professional, especially if the athlete is subjected to drug testing. Moreover, there are laboratories that offer the facility to test dietary supplements for contaminants that are in the WADA list of prohibited substances; therefore, athletes should use this facility to ensure that supplements are safe.

Conclusion

The nutritional requirements for extreme sports vary greatly depending on the type of sport, the environmental conditions and the duration of the activity. Typically, for extreme sports that are longer in duration such as mountaineering, adventure racing, ultra-endurance activities and expedition-type events, the energy demands are much greater, and thus competitors should plan their dietary needs in advance. An inadequate diet and poor fuelling strategies can impair performance and increase the risk of injury and illness during events. Appropriate hydration strategies need to be planned in advance if taking part in extreme environments, and bespoke cooling strategies such as ice slurry ingestion can be used in the heat. Supplements such as caffeine, carbohydrate and dietary nitrates can be used to enhance performance although competitors should check safety and ensure they are batch tested and safe products.

References

1. Jeukendrup AE. Carbohydrate intake during exercise and performance. Nutrition. 2004;20(7):669–77.
2. Burke LM, Kiens B, Ivy JL. Carbohydrates and fat for training and recovery. J Sports Sci. 2004;22(1):15–30.
3. O'Reilly J, Wong SH, Chen Y. Glycaemic index, glycaemic load and exercise performance. Sports Med. 2010;40(1):27–39.
4. Blom PC, Hostmark AT, Vaage O, Kardel KR, Maehlum S. Effect of different post-exercise sugar diets on the rate of muscle glycogen synthesis. Med Sci Sports Exerci. 1987;19(5):491–6.
5. Rodriguez NR, Dimarco NM, Langley S. American Dietetic Association, Dietitians of Canada and American College of Sports Medicine: nutrition and athletic performance. Position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine: nutrition and

athletic performance. J Am Diet Assoc. 2009;109(3):509–27.
6. Burke LM, Cox GR, Cummings NK, Desbrow B. Guidelines for daily carbohydrate intake. Sports Med. 2001;31(4):267–99.
7. Tipton KD, Wolfe RR. Protein and amino acids for athletes. J Sports Sci. 2004;22(1):65–79.
8. Tarnopolsky M. Protein requirements for endurance athletes. Nutrition. 2004;20(7):662–8.
9. Tipton KD, Rasmussen BB, Miller SL, Wolf SE, Owens-Stovall SK, Petrini BE, Wolfe RR. Timing of amino acid-carbohydrate ingestion alters anabolic response of muscle to resistance exercise. Am J Physiol Endocrinol Metab. 2001;281(2):197–206.
10. Koopman R, Saris WH, Wagenmakers AJ, Van Loon LJ. Nutritional interventions to promote post-exercise muscle protein synthesis. Sports Med. 2007;37(10):895–906.
11. Atherton PJ, Smith K. Muscle protein synthesis in response to nutrition and exercise. J Physiol. 2012;590(5):1049–57.
12. Breen L, Phillips SM. Nutrient interaction for optimal protein anabolism in resistance exercise. Curr Opin Clin Nutr Metab Care. 2012;15(3):226–32.
13. Volpi E, Kobayashi H, Sheffield-Moore M, Mittendorfer B, Wolfe RR. Essential amino acids are primarily responsible for the amino acid stimulation of muscle protein anabolism in healthy elderly adults. Am J Clin Nutr. 2003;78(2):250–8.
14. Phillips SM. The science of muscle hypertrophy: making dietary protein count. Proceedings Nutr Society. 2011;70(01):100–3.
15. Moore DR, Robinson MJ, Fry JL, Tang JE, Glover EI, Wilkinson SB, Prior T, Tarnopolsky MA, Phillips SM. Ingested protein dose response of muscle and albumin protein synthesis after resistance exercise in young men. Am J Clin Nutr. 2009;89(1):161–8.
16. Phillips SM, Van Loon LJ. Dietary protein for athletes: from requirements to optimum adaptation. J Sports Sci. 2011;29 Suppl 1:29–38.
17. Murphy CH, Hector AJ, Phillips SM. Considerations for protein intake in managing weight loss in athletes. Euro J of Sport Sci. 2014:1–8. [Ahead-of-Print].
18. Helms ER, Zinn C, Rowlands DS, Brown SR. A systematic review of dietary protein during caloric restriction in resistance trained lean athletes: a case for higher intakes. Int J Sport Nutr Exerc Metab. 2014;24(2):127–38.
19. Josse AR, Atkinson SA, Tarnopolsky MA, Phillips SM. Increased consumption of dairy foods and protein during diet- and exercise-induced weight loss promotes fat mass loss and lean mass gain in overweight and obese premenopausal women. J Nutr. 2011;141(9):1626–34.
20. Ranchordas MK. Nutrition for Adventure Racing. Sports Med. 2012;42(11):915–27.
21. Ranchordas MK, Rogerson D, Ruddock A, Killer S, Winter EM. Nutrition for tennis: practical recommendations. J Sport Sci Med. 2013;12(2):211–24.
22. Maughan R, Noakes T. Fluid replacement and exercise stress. Sports Med. 1991;12(1):16–31.
23. Sawka MN, Pandolf KB. Effects of body water loss on physiological function and exercise performance. Perspectives Exerc Sci Sports Med. 1990;3:1–38.
24. Gopinathan P, Pichan G, Sharma V. Role of dehydration in heat stress-induced variations in mental performance. Archives Environ Health Int J. 1988;43(1):15–7.
25. Rehrer NJ, Beckers EJ, Brouns F, Ten Hoor F, Saris WH. Effects of dehydration on gastric emptying and gastrointestinal distress while running. Med Sci Sports Exerc. 1990;22(6):790–5.
26. O'brien C, Young AJ, Sawka MN, 1. Hypohydration and thermoregulation in cold air. J Appl Physiol (Bethesda, Md: 1985). 1998;84(1):185–9.
27. Seifert JG, Luetkemeier MJ, White AT, Mino LM. The physiological effects of beverage ingestion during cross country ski training in elite collegiate skiers. Can J Appl Physiol. 1998;23(1):66–73.
28. Maughan R, Shirreffs S. Rehydration and recovery after exercise. Sci Sports. 2004;19(5):234–8.
29. Maughan RJ, Shirreffs SM. Nutrition for sports performance: issues and opportunities. Proceedings Nutr Society. 2012;71(01):112–9.
30. Costill D, Sparks K. Rapid fluid replacement for thermal dehydration. Heart. 1973;3:4.
31. Jeukendrup A, Moseley L. Multiple transportable carbohydrates enhance gastric emptying and fluid delivery. Scand J Med Sci Sports. 2010;20(1):112–21.
32. Gonzalez-Alonso J, Heaps C, Coyle E. Rehydration after exercise with common beverages and water. Int J Sports Med. 1992;13(05):399–406.
33. Goulet ED, Lamontagne-Lacasse M, Gigou P, Kenefick RW, Ely BR, Cheuvront S. Pre-exercise hypohydration effects on jumping ability and muscle strength, endurance and anaerobic capacity: a meta-analysis; 1681: Board#118 June 23:30 PM-5:00 PM. Med Sci Sports Exerc. 2010;42(5):362.
34. Gigou P, Lamontagne-Lacasse M, Goulet ED. Meta-analysis of the effects of pre-exercise hypohydration on endurance performance, lactate threshold and Vo2 max: 1679: Board# 116 June 23:30 PM-5:00 PM. Med Sci Sports Exerc. 2010;42(5):361–2.
35. Latzka WA, Sawka MN, Montain SJ, Skrinar GS, Fielding RA, Matott RP, Pandolf KB, 6. Hyperhydration: tolerance and cardiovascular effects during uncompensable exercise-heat stress. J Appl Physiol (Bethesda, Md: 1985). 1998;84(6):1858–64.
36. Latzka WA, Sawka MN, Montain SJ, Skrinar GS, Fielding RA, Matott RP, Pandolf KB. Hyperhydration: thermoregulatory effects during compensable exercise-heat stress. J Appl Physiol (Bethesda, Md: 1985). 1997;83(3):860–6.
37. O'brien C, Freund BJ, Young AJ, Sawka MN. Glycerol hyperhydration: physiological responses during cold-air exposure. J Appl Physiol (Bethesda, Md: 1985). 2005;99(2):515–21.
38. Freund BJ, Montain SJ, Deluca JP, Pandolf KB, Valeri CR. Glycerol hyperhydration: hormonal, renal, and vascular fluid responses. J Appl Physiol. 1995;79:2069–77.

39. Montain SJ, Cheuvront SN, Sawka MN. Exercise associated hyponatraemia: quantitative analysis to understand the aetiology. Br J Sports Med. 2006;40(2):98–105.
40. Kreider RB, Wilborn CD, Taylor L, Campbell B, Almada AL, Collins R, Cooke M, Earnest CP, Greenwood M, Kalman DS. ISSN exercise & sport nutrition review: research & recommendations. J Int Soc Sports Nutr. 2010;7(7):2–43.
41. Marino FE. Methods, advantages, and limitations of body cooling for exercise performance. Br J Sports Med. 2002;36(2):89–94.
42. Tucker R, Marle T, Lambert EV, Noakes TD. The rate of heat storage mediates an anticipatory reduction in exercise intensity during cycling at a fixed rating of perceived exertion. J Physiol. 2006;574(3):905–15.
43. Cheung SS, Mclellan TM, 5. Heat acclimation, aerobic fitness, and hydration effects on tolerance during uncompensable heat stress. J Appl Physiol (Bethesda, Md: 1985). 1998;84:1731–9.
44. Gonzalez-Alonso J, Teller C, Andersen SL, Jensen FB, Hyldig T, Nielsen B, 3. Influence of body temperature on the development of fatigue during prolonged exercise in the heat. J Appl Physiol (Bethesda, Md: 1985). 1999;86(3):1032–9.
45. Cheung SS. Hyperthermia and voluntary exhaustion: integrating models and future challenges. Appl Physiol Nutr Metab. 2007;32(4):808–17.
46. Galloway SD, Maughan RJ. Effects of ambient temperature on the capacity to perform prolonged cycle exercise in man. Med Sci Sports Exerc. 1997;29(9):1240–9.
47. Sawka MN, Coyle EF. Influence of body water and blood volume on thermoregulation and exercise performance in the heat. Exerc Sport Sci Rev. 1999;27(1):167–218.
48. Serwah N, Marino F. The combined effects of hydration and exercise heat stress on choice reaction time. J Sci Med Sport. 2006;9(1):157–64.
49. Marino FE, Mbambo Z, Kortekaas E, Wilson G, Lambert MI, Noakes TD, Dennis SC. Advantages of smaller body mass during distance running in warm, humid environments. Pflugers Arch. 2000;441(2–3):359–67.
50. Lee J, Shirreffs SM, Maughan RJ. Cold drink ingestion improves exercise endurance capacity in the heat. Med Sci Sports Exerc. 2008;40(9):1637–44.
51. Siegel R, Mate J, Brearley MB, Watson G, Nosaka K, Laursen PB. Ice slurry ingestion increases core temperature capacity and running time in the heat. Med Sci Sports Exerc. 2010;42(4):717–25.
52. Siegel R, Maté J, Watson G, Nosaka K, Laursen PB. Pre-cooling with ice slurry ingestion leads to similar run times to exhaustion in the heat as cold water immersion. J Sports Sci. 2012;30(2):155–65.
53. Burdon CA, Hoon MW, Johnson NA, Chapman PG, O'connor HT. The effect of ice slushy ingestion and mouthwash on thermoregulation and endurance performance in the heat. Int J Sport Nutr Exerc Metab. 2013;23:458–69.
54. Ihsan M, Landers G, Brearley M, Peeling P. Beneficial effects of ice ingestion as a precooling strategy on 40-km cycling time-trial performance. Int J Sports Physiol Perform. 2010;5(2):140–51.
55. Kreider RB. Effects of creatine supplementation on performance and training adaptations. Mol Cell Biochem. 2003;244(1-2):89–94.
56. Volek JS, Rawson ES. Scientific basis and practical aspects of creatine supplementation for athletes. Nutrition. 2004;20(7-8):609–14.
57. Sale C, Saunders B, Harris RC. Effect of beta-alanine supplementation on muscle carnosine concentrations and exercise performance. Amino Acids. 2010;39(2):321–33.
58. Hill CA, Harris RC, Kim HJ, Harris BD, Sale C, Boobis LH, Kim CK, Wise JA. Influence of β-alanine supplementation on skeletal muscle carnosine concentrations and high intensity cycling capacity. Amino Acids. 2007;32:225–33.
59. Harris RC, Tallon MJ, Dunnett M, Boobis LH, Coackley J, Kim HJ, Fallowfield JL, Hill CA, Sale C, Wise JA. The absorption of orally supplied β-alanine and its effect on muscle carnosine synthesis in human vastus lateralis. Amino Acids. 2006;30:279–89.
60. Bate-Smith EC. The Buffering of muscle in rigour: protein, phosphate and carnosine. J Physiol. 1938;92:336–43.
61. Hobson RM, Saunders B, Ball G, Harris R, Sale C. Effects of β-alanine supplementation on exercise performance: a meta-analysis. Amino Acids. 2012;43(1):25–37.
62. Pan J, Hamm J, Hetherington H, Rothman D, Shulman R. Correlation of lactate and pH in human skeletal muscle after exercise by 1H NMR. Magn Reson Med. 1991;20(1):57–65.
63. Begum G, Cuncliffe A, Leveritt M. Physiological role of carnosine in contracting muscle. Int J Sport Nutr Exerc Metab. 2005;15(5):493.
64. Vanthienen R, Vanproeyen K, Vanden-Eynde B, Puype K, Lefere T, Hespel P. β-alanine improves sprint performance in endurance cycling. Med Sci Sport Exerc. 2009;41:898–903.
65. Stellingwerff T, Decombaz J, Harris RC, Boesch C. Optimizing human in vivo dosing and delivery of β-alanine supplements for muscle carnosine synthesis. Amino Acids. 2012;43(1):57–65.
66. Bescos R, Sureda A, Tur JA, Pons A. The effect of nitric-oxide-related supplements on human performance. Sports Med. 2012;42(2):99–117.
67. Jones AM. Influence of dietary nitrate on the physiological determinants of exercise performance: a critical review. Appl Physiol Nutr Metab. 2014;39(9):1019–28.
68. Kelly J, Vanhatalo A, Bailey SJ, Wylie LJ, Tucker C, List S, Winyard PG, Jones AM. Dietary nitrate supplementation: effects on plasma nitrite and pulmonary O2 uptake dynamics during exercise in hypoxia and normoxia. Am J Physiol Regul Integr Comp Physiol. 2014;307(7):920–30.
69. Pasman W, Van Baak M, Jeukendrup A, De Haan A. The effect of different dosages of caffeine on

endurance performance time. Int J Sports Med. 1995;16(4):225–30.

70. Bridge C, Jones M. The effect of caffeine ingestion on 8 km run performance in a field setting. J Sports Sci. 2006;24(4):433–9.
71. Burke L. Practical Sports Nutrition. Leeds: Human Kinetics; 2007.
72. Scott JPR, Mcnaughton L. Sleep deprivation, energy expenditure and cardiorespiratory function. Int J Sports Med. 2004;25(6):421–6.
73. Mclellan TM, Kamimori GH, Bell DG, Smith IF, Johnson D, Belenky G. Caffeine maintains vigilance and marksmanship in simulated urban operations with sleep deprivation. Aviat Space Environ Med. 2005;76(1):39–45.
74. Mclellan TM, Kamimori GH, Voss DM, Bell DG, Cole KG, Johnson D. Caffeine maintains vigilance and improves run times during night operations for special forces. Aviat Space Environ Med. 2005; 76(7I):647–54.
75. Campbell C, Prince D, Braun M, Applegate E, Casazza GA. Carbohydrate-supplement form and exercise performance. Int J Sport Nutr Exerc Metab. 2008;18(2):179–90.
76. Saunders MJ, Luden ND, Herrick JE. Consumption of an oral carbohydrate-protein gel improves cycling endurance and prevents postexercise muscle damage. J Strength Cond Res. 2007;21(3):678–84.
77. Burke LM, Wood C, Pyne DB, Telford DR, Saunders PU. Effect of carbohydrate intake on half-marathon performance of well-trained runners. Int J Sport Nutr Exerc Metab. 2005;15(6):573–89.
78. Currell K, Jeukendrup AE. Superior endurance performance with ingestion of multiple transportable carbohydrates. Med Sci Sports Exerc. 2008;40(2): 275–81.
79. Currell K, Urch J, Cerri E, Jentjens RLP, Blannin AK, Jeukendrup AE. Plasma deuterium oxide accumulation following ingestion of different carbohydrate beverages. Appl Physiol Nutr Metab. 2008; 33(6):1067–72.
80. Triplett D, Doyle JA, Rupp JC, Benardot D. An isocaloric glucose-fructose beverage's effect on simulated 100-km cycling performance compared with a glucose-only beverage. Int J Sport Nutr Exer Metab. 2010;20(2):122–31.
81. De Hon O, Coumans B. The continuing story of nutritional supplements and doping infractions. Br J Sports Med. 2007;41:800–5.
82. Maughan RJ. Contamination of dietary supplements and positive drug tests in sport. J Sports Sci. 2005;23:883–9.

3 Endocrine Responses to Extreme Sports

Pawel Jozkow and Marek Medras

3.1 Effects of Regular Exercise on Endocrine Functions

Directly or indirectly, physical activity influences functions of all endocrine glands. However, effects of exercise vary greatly depending on, e.g., type, duration, and intensity of exercise, genetic variants, race, gender, age, body composition, nutritional status, diet, day/season variations, training history, or performance level of an athlete.

Short-time exercise of any kind is associated with significant changes in the hypothalamo-pituitary-adrenal (HPA) axis. Catecholamines (secreted by the adrenal medulla) and cortisol play the key roles here. Concentrations of catecholamines (adrenalin and noradrenalin) may rise severalfold immediately after the beginning of an exercise. They return to basal levels (or lower) 5–10 min after the end of an exercise. Changes of catecholamine levels differ depending on the intensity and the duration of exercise. It is suggested that the reactivity of the adrenal medulla is diminished with aging [1–3].

The secretion of cortisol from the adrenal cortex is stimulated by the pituitary hormone – adrenocorticotropin (ACTH). There is no consensus on the intensity of exercise that is able to activate ACTH secretion. The threshold may be between 30 and 80 % VO_{2max}. Cortisol concentration rises due to endurance rather than power training. Long-distance running or canoeing have higher potency to induce increases in salivary/plasma cortisol than short-time or interval exercise. Similarly, anaerobic exercise changes cortisol stronger than aerobic exercise. The response of the HPA axis to exercise is less pronounced in well-trained individuals [4–6].

Regular training does not influence basal concentrations of ACTH or cortisol. However some data from epidemiological studies indicate that physical activity may be associated with hair cortisol concentration [7].

Generally, overtraining is characterized by reduced ACTH and cortisol responses to stimulation. In overreaching and overtraining syndromes, specific patterns of ACTH and cortisol reactions are observed [8, 9].

Among many beneficial effects of regular exercise, one must underline its effects on glucose metabolism. 10–15 min of exercise exceeding 40 % VO_{2max} is able to reduce insulin secretion by 40 %. Physical training enhances insulin sensitivity by increasing expression of insulin receptors in muscles and stimulating glucose

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utilization. Longer exercise (e.g., 120 min at the intensity of 30–50 % VO_{2max}) is associated with increased secretion of glucagon and increased hepatic gluconeogenesis. Although the influence of exercise on glucose transport to muscle cells lasts up to 120–240 min, insulin sensitivity remains increased for about 48-h postexercise. Expression and activity of GLUT4 (glucose transporter 4) in skeletal muscle is enhanced by endurance training (especially regular) [10–12].

Physical exercise is the strongest physiological stimulus for secretion of growth hormone (GH). Exercise that exceeds 30 % VO_{2max} may lead to tenfold increases in plasma GH concentration. The rise of GH is usually observed within 10–15 min from the start, and it may reach its peak 25–30 min from the beginning of an exercise. GH concentration may stay elevated for more than an hour afterward. IGF-1 follows a similar pattern showing a rise after 10 min of exercise and reaching its peak before 20–40 min from the start of a workout. The greatest response is noted for intensities above the lactate threshold. Exercise of moderate intensity, short intervals between consecutive bouts, and activation of large muscles are associated with stronger response of GH/IGF-1 axis. On the other hand, low temperature, high-fat meal, or obesity may attenuate GH response to exercise.

The reactivity of the GH/IGF-1 axis differs among races; gender differences are of minor importance here. Younger age is associated with greater GH response to exercise. Long-term training has no impact on basal concentrations of GH in both younger and older individuals. Some authors suggested that lower level of fitness correlated with less pronounced GH response; however, it was undermined by others [13–18].

Short-term training (days, weeks) of athletes and non-athletes, men and women, resulted in decreased concentrations of IGF-1. Some authors suggested that lower levels of IGF-1 may indicate overtraining. Training of a longer duration (months) either rises or does not change basal concentrations of IGF-1. However there were published results suggesting the presence of a positive correlation between VO_{2max} and plasma IGF-1 [13, 18, 19].

Only exercise of intensity over 50 % VO_{2max} induces noticeable fluctuations in the components of the pituitary-thyroid axis. The impact of a short-time exercise on thyroid hormones is usually modest and short lived. Reports on changes in concentrations of the thyroxin (T4), triiodothyronine (T3), and free fractions of T4 and T3 (FT4, FT3) brought ambiguous results [20–22].

Many authors observed reduced levels of gonadotropins after intense exercise; however, there were also reports in which gonadotropins did not change or increased. Similarly, some investigators observed 10–25 % rise in testosterone concentration after exercise, but others noted decreased testosterone concentration that remained lower for 13 h after, e.g., resistance exercise. Long-term influence of physical training on androgen concentration is insignificant [13, 23–25].

3.2 Endocrine Responses in Ultra-endurance Sports

The studies on the reactivity of the HPA axis to endurance exercise/training are unequivocal. It seems that HPA axis in Afro-Americans is more sensitive to training than in people of European origin.

For example, intensive, 4-day march (164 km) did not affect basal or postexercise concentration of ACTH in males. However in ultramarathon runners, supraphysiological concentrations of ACTH were observed. Results of some other studies also suggested that this type of training may increase the level of ACTH. In men, repeated 50-km skiing during 2 days (Finlandia Ski Race) increased cortisol concentration 2.2- and 2.6-fold after the races. Covering a distance of 42 km in kayak changed cortisol concentration more than if the distance was 19 km [26–29].

Triathlon can be treated as a flagship of ultra-endurance sports. It combines swimming, cycling, and running in one event. Among five types of triathlon, the Iron distance is the most demanding one. Participants have to complete 3.9-km swim, 180.2-km bike ride, and 42.2-km run. American authors reported significant changes in steroid hormone concentrations in 57 athletes (38 men), taking part in the Hawaii Ironman Triathlon. They have found that this type of exercise induces a clear increase of estradiol (58 %) and a similar decrease of testosterone in men (58 %). In women insignificant increases of estradiol and testosterone were noted [30]. Observations similar to the above were also made in marathon and ultramarathon male runners. On the other hand, there were no significant changes of the hypothalamo-pituitary-gonadal axis in men marching for 4 days (185 km) with the load of 10 kg [27].

According to some authors, marathon runners may have decreased FT3 and increased rT3 (reverse T3) with no change in T3 levels. According to others, marathon running is not associated with any significant changes in the pituitary-thyroid axis [31].

In men who run on skies for 2 days (100 km), LH and testosterone decreased, and there was no change of FSH. Similar observation was made in participants of a several week-long cycling race or soldiers taking part in military training camps. The comparison of the effects of endurance training in professional cyclists, elite triathlonists, recreational marathon runners, and controls leading a sedentary lifestyle showed only modest differences among studied groups. The only significant one was higher concentration of testosterone in cyclists in the preseason period [29]. Japanese authors studied semen and endocrine parameters in members of the Masherbrum expedition in 1999. Three subjects stayed above 5100 m for more than 3 weeks and above 6700 m for 4–5 days. Specimens were collected before the departure and 1, 3, and 24 months after the return from the expedition. There were no changes of semen volume during the study period. Within the first 3 months, a decreased sperm count and decreased testosterone concentration were noted. There were no persistent alterations of the studied parameters after 2 years from the expedition [32].

Ultra-endurance exercise may turn especially dangerous for women. A characteristic threat is the female athlete triad. The syndrome means the presence of disordered eating, menstrual disturbances/infertility, and osteopenia/osteoporosis. It is estimated that 15–62 % of young sportswomen suffer from some kind of eating disorders. The diagnosis is frequently made in disciplines such as gymnastics, ice-skating or running (anorexia athletica is the extreme form of the problem). The percentage of the body fat mass in female athletes is usually 50 % of that found in non-active women. If the fat mass drops below 22 %, it may lead to menstrual irregularities or even amenorrhea. The risk of menstrual disturbances is ten times higher in sportswomen than in general population. They are found in up to 48–66 % of sportswomen. The female triad syndrome may have year-long health consequences. Regular, intense exercise changes pulsatile secretion of GnRH and reduces frequency and amplitude of LH bursts. It is often associated with lower estradiol, increased sex hormone-binding globulin (SHBG) and luteal phase defects. Not fully explained are disturbances of melatonin, thyreotropin, and prolactin. Amenorrhea in young girls has detrimental effects on bone structure and function in adulthood. Decreased concentration of estradiol reduces the peak bone mass which is achieved before the age of 30. BMD of female athletes with amenorrhea is 22–29 % lower than in age-matched regularly menstruating controls. The risk of bone fractures remains elevated in the fourth and fifth decades of life [33, 34].

3.3 Endocrine Responses to Extreme Psychological Stress

Threat and perceived loss of control are capable to elicit psychological stress. Elite sport is associated with psychological stress, though one cannot exclude such a burden in recreational competition either.

Stress activates two main body systems. The immediate response is conveyed by the sympathetic adrenal system. It involves release of adrenalin and noradrenalin. The visible signs of sympathetic stimulation are, e.g, increased heart rate, constriction of peripheral blood vessels, increased blood pressure, sweating, trembling, and dilation of pupils.

The hypothalamo-pituitary-adrenal (HPA) axis plays the key role in the slower hormonal response to stress stimuli. It starts with the secretion of corticotropin-releasing hormone (CRH) from the periventricular nuclei of the hypothalamus. CRH in turn increases secretion of adrenocorticotropin (ACTH). The release of ACTH from the pituitary stimulates secretion of the hormones of the adrenal cortex and medulla. Another hormone that modulates stress reactions is vasopressin (antidiuretic hormone, ADH). It is synthesized in the hypothalamus, and then it is stored in the posterior part of the pituitary. ADH together with CRH increases secretion of ACTH.

Many other hormones are involved in the abovementioned processes. Stress-induced release of neuropeptide Y (NPY) may stimulate production of CRH. Subjects under stressful conditions experience disturbances of central melatonin, dopamine, and serotonin systems. Circadian rhythms in melatonin secretion may be altered. Serotonin concentration may be reduced and dopamine increased. Stress may be associated with decreased production of thyroid-stimulating hormone (TSH).

CRH stimulates production of beta-endorphins by the hypothalamus. Beta-endorphins increase secretion of prolactin and somatostatin. Thus the concentration of growth hormone is reduced. Increased release of CRH interferes with the function the hypothalamo-pituitary-gonadal axis through suppression of the gonadotropin-releasing hormone. There are marked differences in the reactivity of the hypothalamo-pituitary-adrenal axis to stress in men and women [35, 36].

Parachute jumps/skydiving often serve as examples of psychologically stressful situations. Hormonal changes may appear as an anticipatory coping response. Under stressful conditions, significant increases of plasma and urinary catecholamines are observed. On the other hand, acceleration forces during the jump may alter blood flow and lead to two- or threefold increase in catecholamines and plasma cortisol.

Investigations performed in flight rescuers showed that physical effort is associated with increased excretion of adrenalin and noradrenalin in urine, but psychological stress correlates with increased excretion of adrenalin only. In another evaluation of F-15 pilots undertaking a long-distance flight mission, a postflight rise of urine adrenaline and noradrenaline was noted [37].

In a case-control study performed in young volunteers (aged 22–36 years), it has been found that stress on the day of a skydive is associated with increased concentrations of cortisol (plasma and salivary), prolactin, and growth hormone and no increase of plasma testosterone. Salivary testosterone was lower in skydivers as compared with controls throughout the day of the jump. After landing, higher concentrations of LH were noted. Plasma testosterone and cortisol in parachutists were not different to controls [38].

The reaction of GH-IGF-1 axis to psychological stressors is not clear. Generally it is assumed that GH concentration increases in acute stressful situations (skydiving); however, it is not confirmed in all studies. In longer observations of subjects exposed to stress, GH concentration is normal or reduced [39, 40].

The plasma level of prolactin tends to rise due to stress-related anxiety. It was proved for a range of high-risk behaviors including parachute jumping.

Contrary to expectations, experienced skydivers do not habituate to stress associated with jumping. In several experiments, they presented similar reactivity of sympathetic adrenal axis as novices. It was also confirmed for the response of the HPA axis. In a study performed in 13 experienced and 11 first-time divers, the cortisol profiles were no different when evaluated at pre-jump, post-jump, and 1-h post-jump [41].

Breath-hold diving may be associated with a significant psychological stress to participants. Diving practices include staying underwater for several minutes, while the world records go beyond 10 min of apnea and the depths exceed 200 m. Fatalities and serious health complications in breath-hold divers are not rare. For example, exercises of apnea divers comprise up to 20 h of apnea-related training per week. Apnea-induced hypoxia has been suggested to change serum levels of erythropoietin (EPO). In one experiment ten volunteers performed 15 maximal duration apneas (divided in three series separated by 2 min and preceded by 1 min of hyperventilation). After serial apneas EPO concentration increased by 24 % [42].

Our group evaluated serum gonadotropins and androgens in divers: before diving, immediately post, and 60 min after diving. We noted that neither gonadotropins nor total testosterone, free testosterone, calculated free testosterone, or bioavailable testosterone concentrations change significantly due to such practices [43].

On the other hand, authors investigating 109/72 subjects during the US Army survival course observed profound alterations of the thyroid, the adrenals, and the gonads due to acute military stress. During the captivity experience, cortisol increased and testosterone declined. Reductions in free and total thyroxine/triiodothyronine and an increase of TSH were noted [44].

In yet another study, subjects exposed to underwater navigation stress were observed (Combat Diver Qualification Course). Lower baseline concentrations of DHEA and DHEA-S were negatively predictive for stress symptoms of dissociation during the task [45].

References

1. Zouhal H, Gratas-Delamarche A, Rannou F, Granier P, Bentue-Ferrer D, Delamarche P. Between 21 and 34 years of age, aging alters the catecholamine responses to supramaximal exercise in endurance trained athletes. Int J Sports Med. 1999;20(6):343–8.
2. Greiwe JS, Hickner RC, Shah SD, Cryer PE, Holloszy JO. Norepinephrine response to exercise at the same relative intensity before and after endurance exercise training. J Appl Physiol (1985). 1999;86(2):531–5.
3. Baker JS, Bailey DM, Dutton J, Davies B. Catecholamine responses to high intensity cycle ergometer exercise: body mass or body composition? J Physiol Biochem. 2003;59(2):77–83.
4. Tremblay MS, Copeland JL, Van Helder W. Effect of training status and exercise mode on endogenous steroid hormones in men. J Appl Physiol (1985). 2004;96(2):531–9.
5. Kraemer WJ, Fry AC, Warren BJ, Stone MH, Fleck SJ, Kearney JT, et al. Acute hormonal responses in elite junior weightlifters. Int J Sports Med. 1992;13(2):103–9.
6. Inder WJ, Hellemans J, Swanney MP, Prickett TC, Donald RA. Prolonged exercise increases peripheral plasma ACTH, CRH, and AVP in male athletes. J Appl Physiol (1985). 1998;85(3):835–41.
7. Wosu AC, Valdimarsdottir U, Shields AE, Williams DR, Williams MA. Correlates of cortisol in human hair: implications for epidemiologic studies on health effects of chronic stress. Ann Epidemiol. 2013;23(12):797–811.e2.
8. Tanskanen MM, Kyrolainen H, Uusitalo AL, Huovinen J, Nissila J, Kinnunen H, et al. Serum sex hormone-binding globulin and cortisol concentrations are associated with overreaching during strenuous military training. J Strength Cond Res. 2011;25(3):787–97.
9. Meeusen R, Nederhof E, Buyse L, Roelands B, de Schutter G, Piacentini MF. Diagnosing overtraining in athletes using the two-bout exercise protocol. Br J Sports Med. 2010;44(9):642–8.
10. Holloszy JO. Regulation of mitochondrial biogenesis and GLUT4 expression by exercise. Compr Physiol. 2011;1(2):921–40.
11. Rodriguez NR, Di Marco NM, Langley S. American college of sports medicine position stand. Nutrition and athletic performance. Med Sci Sports Exerc. 2009;41(3):709–31.
12. Rodriguez NR, DiMarco NM, Langley S. Position of the American dietetic association, dietitians of Canada, and the American college of sports medicine: nutrition and athletic performance. J Am Diet Assoc. 2009;109(3):509–27.
13. Kraemer WJ, Ratamess NA. Hormonal responses and adaptations to resistance exercise and training. Sports Med. 2005;35(4):339–61.
14. Frystyk J. Exercise and the growth hormone-insulin-like growth factor axis. Med Sci Sports Exerc. 2010;42(1):58–66.
15. Smilios I, Pilianidis T, Karamouzis M, Parlavantzas A, Tokmakidis SP. Hormonal responses after a strength endurance resistance exercise protocol in young and elderly males. Int J Sports Med. 2007;28(5):401–6.
16. Hakkinen K, Pakarinen A, Kraemer WJ, Newton RU, Alen M. Basal concentrations and acute responses of serum hormones and strength development during heavy resistance training in middle-aged and elderly men and women. J Gerontol A Biol Sci Med Sci. 2000;55(2):95–105.
17. Godfrey RJ, Madgwick Z, Whyte GP. The exercise-induced growth hormone response in athletes. Sports Med. 2003;33(8):599–613.
18. Eliakim A, Portal S, Zadik Z, Rabinowitz J, Adler-Portal D, Cooper DM, et al. The effect of a volleyball practice on anabolic hormones and inflammatory markers in elite male and female adolescent players. J Strength Cond Res. 2009;23(5):1553–9.
19. Eliakim A, Nemet D. Exercise training, physical fitness and the growth hormone-insulin-like growth factor-1 axis and cytokine balance. Med Sport Sci. 2010;55:128–40.
20. Kanaka-Gantenbein C. The impact of exercise on thyroid hormone metabolism in children and adolescents. Horm Metab Res. 2005;37(9):563–5.

21. Hackney AC, Dobridge JD. Thyroid hormones and the interrelationship of cortisol and prolactin: influence of prolonged, exhaustive exercise. Endokrynol Pol. 2009;60(4):252–7.
22. Ravaglia G, Forti P, Maioli F, Pratelli L, Vettori C, Bastagli L, et al. Regular moderate intensity physical activity and blood concentrations of endogenous anabolic hormones and thyroid hormones in aging men. Mech Ageing Dev. 2001;122(2):191–203.
23. Linnamo V, Pakarinen A, Komi PV, Kraemer WJ, Hakkinen K. Acute hormonal responses to submaximal and maximal heavy resistance and explosive exercises in men and women. J Strength Cond Res. 2005;19(3):566–71.
24. MacConnie SE, Barkan A, Lampman RM, Schork MA, Beitins IZ. Decreased hypothalamic gonadotropin-releasing hormone secretion in male marathon runners. N Engl J Med. 1986;14;315(7):411–7.
25. Hakkinen K, Pakarinen A. Acute hormonal responses to two different fatiguing heavy-resistance protocols in male athletes. J Appl Physiol (1985). 1993;74(2):882–7.
26. Fellmann N, Bedu M, Boudet G, Mage M, Sagnol M, Pequignot JM, et al. Inter-relationships between pituitary-adrenal hormones and catecholamines during a 6-day Nordic ski race. Eur J Appl Physiol Occup Physiol. 1992;64(3):258–65.
27. Vaananen I, Vasankari T, Mantysaari M, Vihko V. Hormonal responses to daily strenuous walking during 4 successive days. Eur J Appl Physiol. 2002;88(1–2):122–7.
28. Bobbert T, Brechtel L, Mai K, Otto B, Maser-Gluth C, Pfeiffer AF, et al. Adaptation of the hypothalamic-pituitary hormones during intensive endurance training. Clin Endocrinol (Oxf). 2005;63(5):530–6.
29. Vaananen I, Vasankari T, Mantysaari M, Vihko V. Hormonal responses to 100 km cross-country skiing during 2 days. J Sports Med Phys Fitness. 2004;44(3):309–14.
30. Ginsburg GS, O'Toole M, Rimm E, Douglas PS, Rifai N. Gender differences in exercise-induced changes in sex hormone levels and lipid peroxidation in athletes participating in the Hawaii Ironman triathlon. Ginsburg-gender and exercise-induced lipid peroxidation. Clin Chim Acta. 2001;305(1–2):131–9.
31. Semple CG, Thomson JA, Beastall GH. Endocrine responses to marathon running. Br J Sports Med. 1985;19(3):148–51.
32. Okumura A, Fuse H, Kawauchi Y, Mizuno I, Akashi T. Changes in male reproductive function after high altitude mountaineering. High Alt Med Biol. 2003;4(3):349–53.
33. Brunet 2nd M. Female athlete triad. Clin Sports Med. 2005;24(3):623–36.
34. Nattiv A, Agostini R, Drinkwater B, Yeager KK. The female athlete triad. The inter-relatedness of disordered eating, amenorrhea, and osteoporosis. Clin Sports Med. 1994;13(2):405–18.
35. Gallucci WT, Baum A, Laue L, Rabin DS, Chrousos GP, Gold PW, et al. Sex differences in sensitivity of the hypothalamic-pituitary-adrenal axis. Health Psychol. 1993;12(5):420–5.
36. Tsigos C, Kyrou I, Chrousos G. Stress, endocrine physiology and pathophysiology. Dartmouth: MDTEXT.COM, INC; 2004. www.endotext.com.
37. Ohrui N, Kanazawa F, Takeuchi Y, Otsuka Y, Tarui H, Miyamoto Y. Urinary catecholamine responses in F-15 pilots: evaluation of the stress induced by long-distance flights. Mil Med. 2008;173(6):594–8.
38. Chatterton Jr RT, Vogelsong KM, Lu YC, Hudgens GA. Hormonal responses to psychological stress in men preparing for skydiving. J Clin Endocrinol Metab. 1997;82(8):2503–9.
39. Noel GL, Dimond RC, Earll JM, Frantz AG. Prolactin, thyrotropin, and growth hormone release during stress associated with parachute jumping. Aviat Space Environ Med. 1976;47(5):534–7.
40. Richter SD, Schurmeyer TH, Schedlowski M, Hadicke A, Tewes U, Schmidt RE, et al. Time kinetics of the endocrine response to acute psychological stress. J Clin Endocrinol Metab. 1996;81(5):1956–60.
41. Hare OA, Wetherell MA, Smith MA. State anxiety and cortisol reactivity to skydiving in novice versus experienced skydivers. Physiol Behav. 2013;13(118):40–4.
42. De Bruijn R, Richardson M, Schagatay E. Increased erythropoietin concentration after repeated apneas in humans. Eur J Appl Physiol. 2008;102(5):609–13.
43. Jozkow P, Medras M, Chmura J, Kawczynski A, Morawiec B. Effect of breath-hold diving (freediving) on serum androgen levels -- a preliminary report. Endokrynol Pol. 2012;63(5):381–7.
44. Morgan 3rd CA, Wang S, Mason J, Southwick SM, Fox P, Hazlett G, et al. Hormone profiles in humans experiencing military survival training. Biol Psychiatry. 2000;47(10):891–901.
45. Morgan 3rd CA, Rasmusson A, Pietrzak RH, Coric V, Southwick SM. Relationships among plasma dehydroepiandrosterone and dehydroepiandrosterone sulfate, cortisol, symptoms of dissociation, and objective performance in humans exposed to underwater navigation stress. Biol Psychiatry. 2009;15;66(4):334–40.

Infectious Diseases and Extreme Sports

4

Ricardo Pereira Igreja

4.1 Introduction

Recent outbreaks of infectious diseases in competitive sports have stimulated considerable interest in the role of infections in the health of athletes. Sports provide an excellent opportunity for the transmission of communicable diseases to athletes, athletic staff, and social contacts, propagating the outbreak into the community. Furthermore, the increasing popularity of international sporting events is likely to expose athletes to indigenous diseases for which they have little, if any, natural immunity [1].

Adventure travel has led to an increasing risk for contact with pathogens uncommon in industrialized countries. Extreme sport athletes may be at increased risk because they often travel through poorer, rural areas of tropical and subtropical regions to reach their destinations. In addition, competitions can take place in extreme locations like jungles, mountains, or deserts. Risk from a specific infectious agent depends on the region of the world traveled, contact with food or water, and whether traveling in rural or urban area [2].

Common sources of exposure include contaminated lakes, rivers, caves, and canyons. Athletes may be exposed to insect vectors. African ticks were responsible for an outbreak of African tick-bite fever in participants of an Eco-challenge [3].

Besides the lack of immediate medical care that can complicate and worsen the severity of these diseases, these illnesses may be unfamiliar to practitioners in the travelers' home countries, and symptoms may go unrecognized. Physicians caring for extreme sport competitors must take a careful travel and exposure history and have a high index of suspicion for unusual diseases.

4.2 Infectious Diseases and Extreme Sports

The following discusses infections that may be more likely to occur in the extreme sport athlete. Epidemiology, presentation, and prophylaxis are discussed for each of these diseases. Infections that were solely food borne were excluded.

4.2.1 Malaria

Malaria continues to be a major global health problem, with over 40 % of the world's population—more than 3.3 billion people—at risk for malaria to varying degrees in countries with ongoing transmission (transmission still occurs in 99 countries). In addition, with modern, rapid means of travel, large numbers of people from nonmalarious areas are being infected,

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which may seriously affect them after they have returned home. *Plasmodium falciparum* is common in the tropics and causes the most serious form of the disease. The risk of severe malaria is increased if treatment of an uncomplicated attack of malaria is delayed. As infections with this parasite can be fatal, recognizing and promptly treating uncomplicated malaria is therefore of vital importance. The presentation of uncomplicated *P. falciparum* malaria is highly variable and mimics that of many other diseases. Although fever is common, it may be absent in some cases. The fever is typically irregular initially and commonly associated with chills. The patient commonly complains of fever, headache, aches, and pains elsewhere in the body and occasionally abdominal pain and diarrhea. On physical examination, fever may be the only sign. In some patients, the liver and spleen are palpable. This clinical presentation is usually indistinguishable clinically from those of influenza and a variety of other common causes of fever. Unless the condition is diagnosed and treated promptly, a patient with *P. falciparum* malaria may deteriorate rapidly [4].

All travelers to areas with malaria risk are advised to use personal protective measures to prevent bites from *Anopheles* mosquitoes. Because of the nocturnal feeding habits of *Anopheles* mosquitoes, malaria transmission occurs primarily between dusk and dawn. Mosquito repellents containing DEET (N,N-diethyl-3-methylbenzamide) are especially useful for protection during outdoor activities. They should be applied to exposed skin surfaces and repeated after 4–6 h. Repellents should not be sprayed on the face nor applied to lips or eyelids, and the dosage should not be exceeded, especially for small children. Icaridin (picaridin) and *P-menthane-3,8-diol* (lemon eucalyptus oil) may be used as a second-line alternative repellent. If travelers are also wearing sunscreen, sunscreen should be applied first and insect repellent second. Combining DEET and permethrin-impregnated clothing enhances protection against biting arthropods. Insecticide-treated (permethrin) mosquito nets have been proven effective and are advised for all travelers visiting disease-endemic areas where they are at risk from biting arthropods while sleeping [5].

The decision as to whether chemoprophylaxis is necessary depends on the areas to be visited and the risk that the traveler has of being exposed to mosquitoes and of developing malaria. The greater the traveler's risk of contracting malaria and developing complications, the greater the need for chemoprophylaxis. When deciding on the need for chemoprophylaxis, it must be remembered that all medicines have adverse effects and that the risk of developing a serious adverse effect must be weighed against the risk of developing malaria. Doxycycline, chloroquine, atovaquone-proguanil, or mefloquine can be used prophylactically. Mefloquine does lower the seizure threshold, and its side effects could potentially be confused with decompression or narcosis events. It should also be noted that some sub-aqua centers do not permit those taking mefloquine to dive. Mefloquine might therefore be better avoided for those undertaking diving holidays, but there is no contraindication to its use in occasional divers who have taken and tolerated the drug before, or those able to start taking it early to ensure that no adverse events occur. Dizziness is one of the side effects that have occurred in chemoprophylaxis studies. Doxycycline may cause photosensitivity which is mostly mild and transient. The prescriber should warn against excessive sun exposure (and advise on the correct use of a broad spectrum sunscreen) [6]. No chemoprophylaxis is 100 % effective. However, disease in those taking chemoprophylaxis is likely to be milder or less rapidly progressive even if the parasites exhibit a degree of drug resistance. Chemoprophylaxis needs to be used in addition to, and not instead of, personal protection measures. The most reliable way of preventing malaria is to avoid mosquito bites.

4.2.2 Myiasis

Myiasis is the infestation of live humans and vertebrate animals by fly larvae. The risk of a traveler's acquiring a screwworm infestation has been considered negligible, but with the increasing popularity of adventure sports and wildlife travel, this risk may need to be reassessed. One case was reported in a Finnish man, who was participating in an international adventure sports race in Pará (a jungle area in Brazilian Amazon), and tripped at night over a loose rock while he was riding a bicycle [7].

Myiasis occurs in tropical and subtropical areas. People typically get the infection when they travel to tropical areas in Africa and South America. People traveling with untreated and open wounds are more at risk for getting myiasis.

Even physicians unfamiliar with this condition can easily diagnose cases in which maggots are visible. On the other hand, furuncular, migratory, and cavitary cases and pseudomyiasis pose a diagnostic challenge, especially to those doctors unacquainted with myiasis and its possibilities [8]. Fly larvae need to be surgically removed.

Preventing possible exposure is key advice for patients traveling in endemic areas. In regions of endemicity, sleeping nude, outdoors, and on the floor should be avoided. Appropriate precautions will help avoid infestations. The use of screens and mosquito nets is essential to prevent flies from reaching the skin. Some fly species infestation may be thwarted by the application of insect repellents containing DEET. Drying clothes in bright sunlight and ironing them are effective methods of destroying occult eggs laid in clothing. Other general precautions include wearing long-sleeved clothing and covering wounds [8].

4.2.3 Schistosomiasis

Human schistosomiasis is a major health issue in many parts of Africa, Asia, and Latin America. It is estimated that 200 million people, in 76 countries, are infected with one of the schistosome species that cause the disease [9]. Most infections worldwide are attributable to three species: *Schistosoma mansoni*, *S. haematobium*, and *S. japonicum*. Infection in humans comes from water contact, and transmission occurs via the penetration of larval cercariae in contaminated freshwater.

Schistosomiasis in travelers is well established, including outbreaks among athletes after freshwater exposure, mainly prolonged exposure, such as rafting or kayak competition [10, 11].

Many of the travelers, who have never been exposed to the disease, can develop its acute form. Acute schistosomiasis is a transient hypersensitivity syndrome that is caused by the juvenile forms of *Schistosoma* species. The clinical manifestations of this syndrome appear 2–8 weeks after exposure, and the common manifestations are fever, urticaria, malaise, cough, myalgia, and gastrointestinal complaints [12]. As asymptomatic schistosomiasis in travelers is also common (43 % in one series) [11], all travelers exposed to freshwater in endemic areas should be encouraged to undergo screening tests.

No vaccine is available. No drugs for preventing infection are available. Preventive measures are primarily avoiding wading, swimming, or other contact with freshwater in disease-endemic countries. Untreated piped water coming directly from freshwater sources may contain cercariae, but filtering with fine mesh filters, heating bathing water to 122 °F (50 °C) for 5 min, or allowing water to stand for ≥24 h before exposure can eliminate risk for infection. Swimming in adequately chlorinated swimming pools is virtually always safe, even in disease-endemic countries. Vigorous towel drying after accidental exposure to water has been suggested as a way to remove cercariae before they can penetrate, but this may only prevent some infections and should not be recommended as a preventive measure. Topical applications of insect repellents such as DEET can block penetrating cercariae, but the effect depends on the repellent formulation, may be short lived, and cannot reliably prevent infection [13].

4.2.4 Rickettsiosis

Tickborne rickettsial diseases (TBRD) are clinically similar yet epidemiologically and etiologically distinct illnesses. TBRD continue to cause severe illness and death in otherwise healthy adults and children, despite the availability of low cost, effective antimicrobial therapy [14].

Tickborne diseases potentially pose a threat to athletes who participate in outdoor activities. In France, 13 cases of *R. africae* infection were diagnosed in competitors returning from an adventure race in South Africa [3].

The greatest challenge to clinicians is the difficult diagnostic dilemma posed by these infections early in their clinical course, when antibiotic therapy is most effective. Early signs and symptoms of these illnesses are notoriously nonspecific or mimic benign viral illnesses, making diagnosis difficult [14].

No licensed vaccines for TBRD exist. Avoiding tick bites and promptly removing attached ticks remain the best disease prevention strategies. Protective clothing, including a hat, long-sleeved shirts, pants, socks, and closed-toe shoes are helpful in preventing ticks from reaching the skin and attaching. Wearing light-colored clothing is preferred because crawling ticks can be seen easily. Prevention is best accomplished by applying a deet-containing repellent before outdoor activities. Products containing permethrin can be used to treat outer clothing (e.g., shirts and pants) and should not be applied to skin.

If an attached tick is found, it should be removed by grasping with tweezers or fine-tipped forceps close to the skin and gently pulling with constant pressure. Folk remedies—including gasoline, kerosene, petroleum jelly, fingernail polish, or lit matches—should never be used to extract ticks. Removing the tick with bare hands should be avoided because fluids containing infectious organisms might be present in the tick's body and at the wound site. Ticks that have been removed should not be crushed between the fingers to prevent contamination, and hands should be washed to avoid potential conjunctival inoculation. The bite wound should then be disinfected [14].

4.2.5 Leptospirosis

Leptospirosis is a worldwide public health problem, but it is a greater problem in humid tropical and subtropical areas, where most developing countries are found, than in temperate climates. The disease is associated with exposure to water or soil that has been contaminated by a variety of wild and domestic animals, which serve as reservoirs for leptospires and transmit infection by shedding the organisms in their urine. Humans are usually infected through abraded skin or mucous membrane contact with water contaminated by the urine of animal reservoirs, and less frequently by direct contact with animals or their urine [15].

Increased interest in participation in water sports has led to an increase in the frequency that leptospirosis has been reported in association with a variety of recreational sport activities. Outbreaks of leptospirosis have been associated with caving, canoeing, kayaking, rafting, triathlons, and multisport races in distinct places such as Thailand, Costa Rica, Martinique, Malaysia, the Philippines, and USA (Wisconsin, Illinois, and Florida) [15, 16]. At least 68 cases of leptospirosis occurred in association with the multisport Eco-Challenge event in Borneo, in which on univariate analysis, statistically significant risk factors for illness included kayaking, swimming in the Segama River, swallowing water from the Segama River, and spelunking[17].

Clinicians should have a high index of suspicion for leptospirosis in patients who experience acute febrile illness after recreational exposure to natural bodies of fresh water. The diagnosis of leptospirosis should be considered in any patient presenting with an abrupt onset of fever, chills, conjunctival suffusion, headache, myalgia, and jaundice. The incubation period is usually 5–14 days, with a range of 2–30 days. Its symptoms may mimic those of a number of other unrelated infections such as influenza, meningitis, hepatitis, or dengue and viral hemorrhagic fevers. For this reason, it is important to distinguish leptospirosis from dengue and viral hemorrhagic fevers in patients acquiring infections in countries where these diseases are endemic [5].

The first steps of prevention in athletes should be to avoid swimming in rivers, swallowing lake or river water, and prevent dermal cuts [15]. Transmission can be prevented by wearing protective clothing (boots, gloves, spectacles, masks), covering skin lesions with waterproof dressings, washing or showering after exposure to urine or contaminated soil or water, and washing and cleaning wounds [18]. Such preventive measures are important but may not be feasible or sufficient for athletes who are likely to have water immersion, so they should consider doxycycline prophylaxis, balancing the risk of unwanted side effects against that of acquiring leptospirosis. Usual leptospirosis prophylaxis (200 mg of doxycycline once a week) for cavers may be insufficient. Although unproven, cavers should consider augmenting daily or weekly prophylaxis by adding 200 mg of doxycycline at a time for any high-risk exposures—such as immersions, swallowing river water, or contacts with bat or rat urine [19]. When occupational, recreational, or social circumstances put people at risk, those concerned should be made aware of the symptoms of leptospirosis and, if an illness compatible with leptospirosis develops, should seek medical help without delay and inform the health-care provider about the exposure [18].

4.2.6 Rabies

Rabies is a zoonotic disease caused by ribonucleic acid (RNA) viruses in the family *Rhabdoviridae*, genus *Lyssavirus*. Rabies is transmitted by infected animal bites or scratches or by contamination of abrasions, open wounds, or mucous membranes by infectious material (almost always saliva). The main transmitter of this virus to humans in urban areas is the domestic dog. In countries where urban rabies has been controlled by the authorities, great attention has been given to sylvatic rabies, where the virus has been isolated in several animal species (raccoons, skunks, and foxes and various species of bats and nonhuman primates), in addition to proven cases of human rabies by contact with these animals. Exposures to bats deserve special assessment because bats can pose a greater risk for infecting humans under certain circumstances that might be considered inconsequential from a human perspective (i.e., a minor bite or lesion).

Globally, rabies is the tenth leading cause of death due to infection in humans. The threat of rabies exists in most parts of the world. Predominantly, it affects poor people in developing countries, and its true incidence may be underestimated. In the year 2005, there were reports estimating that nearly 60,000 human fatalities occur each year mostly in Asia and Africa. A WHO-sponsored multicentric study estimated that at least 20,000 deaths occurred annually in India alone [20].

International travelers to areas where canine rabies remains enzootic are at risk for exposure to rabies from domestic and feral dogs. Dog bites in off-road cyclists were reported [21].

After entering the central nervous system, the virus causes an acute, progressive encephalomyelitis that is almost always fatal. The incubation period in humans usually ranges from 1 to 3 months after exposure but can range from days to years. Rabies should be included in the differential diagnosis of any unexplained acute, rapidly progressive encephalitis, especially in the presence of autonomic instability, dysphagia, hydrophobia, paresis, or paresthesia [5].

Rabies can be prevented by avoidance of viral exposure and initiation of prompt medical intervention when exposure does occur. In general, people know that dogs and cats can transmit rabies, but they are unaware that bats, foxes, monkeys, and other wild animals are also transmitters of the disease. So, they do not seek medical care after being bitten by these animals and thus are at serious risk of being victims of rabies [22]. Preexposure vaccination should be considered for persons whose activities bring them into frequent contact with the rabies virus or potentially rabid bats, raccoons, skunks, cats, dogs, or other at-risk species. Although cavers seldom have direct contact with bats, they are included in a frequent-risk category by the current CDC recommendations for preexposure vaccination because of the potential for bite, nonbite, or aerosol exposure to the rabies virus [23].

After any potentially rabid animal exposure, immediate washing and flushing of the wound with soap and water is imperative and is probably the most effective procedure in the prevention of rabies. Prompt wound care and the administration of rabies immune globulin and vaccine are highly effective in preventing human rabies following exposure.

Conclusion

Infections may occur during outdoor activities and to reduce the risk of illness while practicing extreme sports, knowledge of potential risks before engaging in these activities is important. General recommendations are prophylactic medications; vaccine should be updated; athletes should resist the temptation to approach animals and to maintain minimum distances from them at all times; and advice regarding other protective measures.

As outdoor activities become increasingly popular, health-care providers will be forced to recognize the unique niche that wilderness medical care occupies in this patient population, and it will become important for them to understand the nature of illness experienced by outdoor enthusiasts in their specific area of patient care.

References

1. Turbeville SD, Cowan LD, Greenfield RA. Infectious disease outbreaks in competitive sports. A review of the literature. Am J Sports Med. 2006;34(11):1860–5.
2. Young CC, Niedfeldt MW, Gottschlich LM, Peterson CS, Gammons MR. Infectious disease and the extreme sport athlete. Clin Sports Med. 2007;26:473–87.
3. Fournier P-E, Roux V, Caumes E, Donzel M, Raoult D. Outbreak of *Rickettsia africae* infections in participants of an adventure race in South Africa. Clin Infect Dis. 1998;27:316–23.
4. World Health Organization. Management of severe malaria: a practical handbook. 3rd ed. Geneva: The Organization; 2012.
5. Igreja RP. Infectious diseases associated with caves. Wilderness Environ Med. 2011;22:115–21.
6. Chiodini PL, Field VK, Hill DR, Whitty CJM, Lalloo DG. Guidelines for malaria prevention in travellers from the United Kingdom. London: Public Health England; 2013.
7. Seppanen M, Virolainen-Julkunen A, Kakko I, Vilkamaa P, Meri S. Myiasis during adventure sports race. Emerg Infect Dis. 2004;10(1):137–9.
8. Francesconi F, Lupi O. Myiasis. Clin Microbiol Rev. 2012;25(1):79–105.
9. Igreja RP, Matos JA, Goncalves MM, Barreto MM, Peralta JM. *Schistosoma mansoni*-related morbidity in a low prevalence area in Brazil: a comparison between egg-excretors and *S. mansoni* antibody positive individuals. Ann Trop Med Parasitol. 2007;101(7):575–84.
10. Morgan OW, Brunette G, Kapella BK, et al. Schistosomiasis among recreational users of upper Nile river, Uganda, 2007. Emerg Infect Dis. 2010;16:866–8.
11. Schwartz E, Kozarsky P, Wilson M, Cetron M. Schistosome infection among river rafters on Omo river, Ethiopia. J Travel Med. 2005;12:3–8.
12. Lachish T, Tandlich M, Grossman T, Schwartz E. High rate of schistosomiasis in travelers after a brief exposure to the high-altitude Nyinambuga crater lake. Uganda Clin Infect Dis. 2013;57(10):1461–4.
13. Montgomery S. Schistosomiasis. In: Centers for Disease Control and Prevention. CDC Health Information for International Travel 2008. Atlanta: US Department of Health and Human Services, Public Health Service; 2007. p. 297–301.
14. Centers for Disease Control and Prevention. Diagnosis and management of tickborne rickettsial diseases: rocky mountain spotted fever, ehrlichioses, and anaplasmosis—United States: a practical guide for physicians and other health-care and public health professionals. MMWR Recomm Rep. 2006;55:1–27.
15. Hochedez P, Rosine J, Théodose R, Abel S, Bourhy P, Picardeau M, Quénel P, Cabié A. Outbreak of leptospirosis after a race in the tropical forest of Martinique. Am J Trop Med Hyg. 2011;84(4):621–6.
16. Haake DA, Dundoo M, Cader R, Kubak BM, Hartskeer RA, Sejvar JJ, Ashford DA. Leptospirosis, water sports, and chemoprophylaxis. Clin Infect Dis. 2002;34:40–3.
17. Sejvar J, Bancroft E, Winthrop K, Bettinger J, Bajani M, BraggS SK, Kaiser R, Marano N, Popovic T, Tappero J, Ashford D, Mascola L, Vugia D, Perkins B, Rosenstein N. Leptospirosis in "Eco-Challenge" athletes, Malaysian Borneo 2000. Emerg Infect Dis. 2003;9:702–7.
18. World Health Organization. Human leptospirosis: guidance for diagnosis, surveillance and control. Geneva: The Organization; 2003.
19. Mortimer RB. Leptospirosis in a caver returned from Sarawak, Malaysia. Wilderness Environ Med. 2005;16:129–31.
20. World Health Organization. Rabies and envenomings: a neglected public health issue: report of a consultative meeting, WHO, Geneva, 10 January 2007. Geneva: The Organization; 2007.
21. Ansari M, Shafiei M, Kordi R. Dog bites among off-road cyclists: a report of two cases. Asian J Sports Med. 2012;3(1):60–3.
22. Pereira IR. Potential hazards for infectious diseases transmitted by wild animals during physical activity in the Tijuca National Park, Rio de Janeiro, Brazil. Gazzetta Medica Italiana Archivio per le Scienze Mediche. 2013;172(12):963–7.
23. Centers for Disease Control and Prevention. Use of a reduced (4-dose) vaccine schedule for postexposure prophylaxis to prevent human rabies recommendations of the advisory committee on immunization practices. MMWR. 2010;59(RR-2):1–10.

Ocular Problems in Extreme Sports

5

High-Altitude Trekking and Surfing

Martina M. Bosch, Pascal B. Knecht,
and Stephanie Watson

5.1 High-Altitude Trekking

Traveling to high altitudes for recreational reasons is becoming increasingly popular among healthy lowlanders. Besides increasing exposure to irradiation, trekkers experience changes in the body due to hypobaric hypoxic conditions depending on the altitudes they travel to.

Solar energy can cause a variety of damage to the human body. Depending on the wavelength, light can affect different structures of the eye. Fortunately, ultraviolet light (UV-C, ca. 200–290 nm wavelength) from the sun is completely absorbed in the upper atmosphere and is thus not considered a hazard to the eye, even at very high altitudes. UV-A (320–380 nm wavelength) and UV-B (290–320 nm wavelength) and visible light (380 to ca. 700 nm wavelength), on the other hand, do reach the eye at different mountaineering altitudes, and depending on which structure absorbs the energy, different trauma may be inflicted.

As a consequence of inflicted hypoxia to unacclimatized individuals with a consecutive decrease in oxygen saturation (SpO2), high-altitude climbing may lead to a complex of altitude-related illness (AI), which also includes acute mountain sickness (AMS), high-altitude retinopathy (HAR), the potentially fatal high-altitude cerebral edema (HACE), and high-altitude pulmonary edema (HAPE) [1–3]. Independent risk factors for the development of AI are considered to be the maximum altitude climbed, individual susceptibility, and ascent rate [4, 5].

5.2 Hypoxia

5.2.1 Anterior Segment Changes

Not many pathological changes to the anterior segment of the eye have been linked to hypoxic exposure. Despite evidence of corneal swelling at high altitudes which is promoted by low SpO2, visual acuity in healthy corneas has not been shown to be adversely affected [6]. Also, contact lens wear, which per se induces hypoxic changes to the cornea, has shown to induce higher levels of manifested stresses without seriously affecting visual acuity and thus not precluding normal wear of soft contact lenses at high altitudes [7]. Hypobaric hypoxia at very high altitude leads to

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small but statistically significant changes in IOP that are modulated by systemic oxygen saturation. Climbs to very high altitudes seem to be safe with regard to intraocular pressure changes [8].

5.2.1.1 Refractive Changes in Trekkers Following Refractive Surgery to the Cornea

Besides AMS, corneal changes during high-altitude climbs may also be a dangerous hazard owing to a potential significant decrease in visual acuity in trekkers who have had prior corneal refractive surgery. The documented experience of Dr. Beck Weathers, a Mount Everest climber who had undergone radial keratotomy prior to ascent and incurred severe vision loss during the climb, is such an example. There is a myriad of different approaches to surgery for patients with the goal to become spectacle-free. In earlier days, radial cuts into the cornea were performed; this technique has been widely abandoned, and excimer and femtosecond lasers are currently employed for laser in situ keratomileusis (LASIK), laser epithelial keratomileusis (LASEK), photorefractive keratectomy (PRK), femtosecond lenticule extraction (FLEx), and small incision lenticule extraction (SmILE) procedures. These procedures are still evolving in order to correct refractive errors without damaging the architecture of the cornea too extensively.

Previous research has demonstrated that surface hypoxia can induce a prominent hyperopic shift in people who have undergone radial keratotomy [9, 10] but does not seem to influence the refractive stability of PRK. Case series have been published where a myopic shift appears to occur in climbers who have undergone LASIK and subsequently exposed to hypoxia [11, 12]. These changes were reported to disappear after arrival back at sea level. The amount of hyperopic or myopic shift seems to diminish with increased postoperative time [9]. The effect of altitude exposure on patients after different refractive surgery techniques remains unpredictable and represents a potential hazard to high-altitude trekkers.

Treatment Affected trekkers might consider bringing along spectacles with the anticipated change in refractive error after refractive surgery to increase visual acuity during the climb.

Prevention Waiting at least 6 months after refractive surgery may be wise prior to attempting a climb to high altitudes.

5.2.2 Posterior Segment Changes

Different pathological posterior segment changes have been documented during high-altitude trekking.

5.2.2.1 High-Altitude Retinopathy

High-altitude retinal hemorrhages (HARH) (Fig. 5.1) often go unnoticed by the affected trekker and can usually be seen ca. 3500 m above sea level [13, 14]. The estimated incidence of HARH is reported to vary from 0 % [15] to 79 % [16]. Climbers who sustain longer and more extensive systemic hypoxia during the expedition present with more HARH [16, 17]. HARH may be seen more

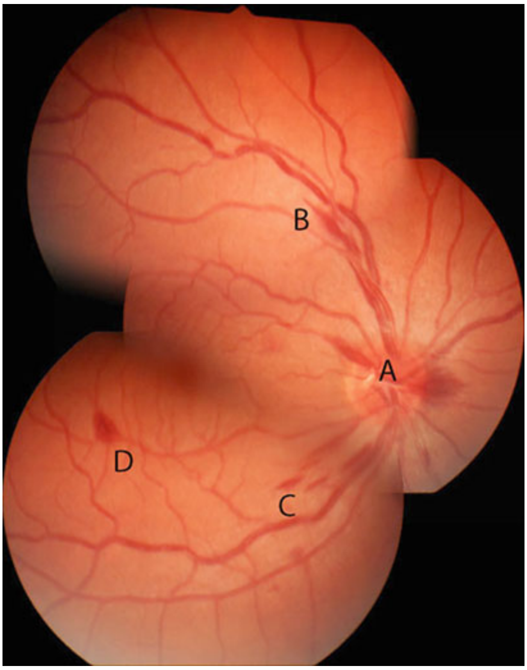

Fig. 5.1 High-altitude retinopathy. This fundus photograph shows the retina of a high-altitude climber at 6870 m, who participated in the Muztagh Ata study in 2005. Shown are (*A*) peripapillary hemorrhages, (*B, C*) retinal hemorrhages at the temporal retinal vessels, (*D*) a white-centered hemorrhage (Roth spot) within the macular region, and (*A*) early signs of optic disk swelling (Schnetzler et al. 2006)

often in young and physically fit mountaineers—especially in those who undergo strenuous exercise at high altitudes [18–20]. To date, there are no correlations between the incidence of HARH and intake of medication such as diuretics, nonsteroidal anti-inflammatory drugs, or steroids.

Signs of high-altitude retinopathy (HAR) include retinal hemorrhages (HARH), engorgement and tortuosity of retinal vessels, optic disk hyperemia and swelling, cotton wool spots, and even vitreous hemorrhage [15, 17, 21–23]. Both central retinal vein occlusion [24] and branch retinal vein occlusion with macular edema [19] inducing loss of visual acuity have been reported in association with altitude retinopathy. A subset of climbers show white-centered hemorrhages [17, 25], also known as Roth spots [26]. This specific type of bleeding observed at sea level occurs in patients with capillary fragility due to systemic infections, hypertension, diabetes [27], anemia, and leukemia [28]. High-altitude climbers with Roth spots often present with larger retinal hemorrhages compared to climbers without white-centered hemorrhages [16]. As mentioned earlier, retinal hemorrhages during high-altitude trekking are usually not symptomatic. However, depending on the location of the hemorrhage, there is a rare possibility that visual acuity will be markedly impaired, such as in foveal bleeding, especially if bilateral. If the latter occurs, aided descent would be necessary, as reabsorption of the blood may take days to weeks, depending on the severity of the hemorrhage.

Treatment Similar to retinal hemorrhages occurring at sea level for different reasons, high-altitude retinal hemorrhages usually disappear within days or a few weeks without sequelae. Thus, the usual treatment protocol is to watch and wait for their resolution. Other HAR entities such as vein occlusions also require follow-up and may eventually need specific ophthalmic treatment.

Prevention Adequate acclimatization will help to defer altitude illness. To date, no medication has been reported as successful in preventing retinal hemorrhages. Since HARH are of transient nature, there is no good evidence to discourage climbers who have experienced prior symptomatic retinal hemorrhages from going back to high altitude. If visual disturbances, which have occurred during a sojourn to high altitudes, do not resolve within a week, the climber should consult an ophthalmologist within maximally another week. Since there is no clear evidence that retinal hemorrhages are warning signs of impending severe acute mountain sickness or even high-altitude cerebral edema, continuation of the expedition can be ventured—under the premise that the climber is never alone during the further sojourn at high altitudes and only if visual disturbances due to retinal bleeding are minimal and do not impede the safety of the climb [29].

5.2.2.2 Optic Disk Swelling

Optic disk swelling (Fig. 5.2) has been reported to occur in up to 79 % of mountaineers at altitudes of 4560 m [20] and in up to at least 59 % of mountaineers at altitudes of 6800 m above sea level, increasing in incidence with ascent to higher altitudes and regressing quickly upon descent [30]. A correlation with low peripheral oxygen saturation and symptoms of acute mountain sickness has been reported in 27 climbers, concluding that optic disk swelling is most likely the result of hypoxia-induced brain volume increase [30]. This has been debated by Willman et al. [20], who did not find a correlation between optic disk swelling and symptoms of acute mountain sickness in 18 mountaineers. A possible explanation for this discrepancy is the different ascent profiles (rapid vs. slow) and the different heights reached in the two studies (4559 m and 6800 m).

Treatment Since quick regression of optic disk swelling is seen upon descent and no lasting sequelae have been reported up till now, the mainstay of treatment is similar to further altitude illness entities where descending to lower altitudes is necessary. This option should be considered if symptoms and signs of AMS or HACE are detected.

Prevention As for HAR, prudent selection of adequate climbing profiles with necessary acclimatization is certainly beneficial to the climber's well-being during high-altitude sojourns.

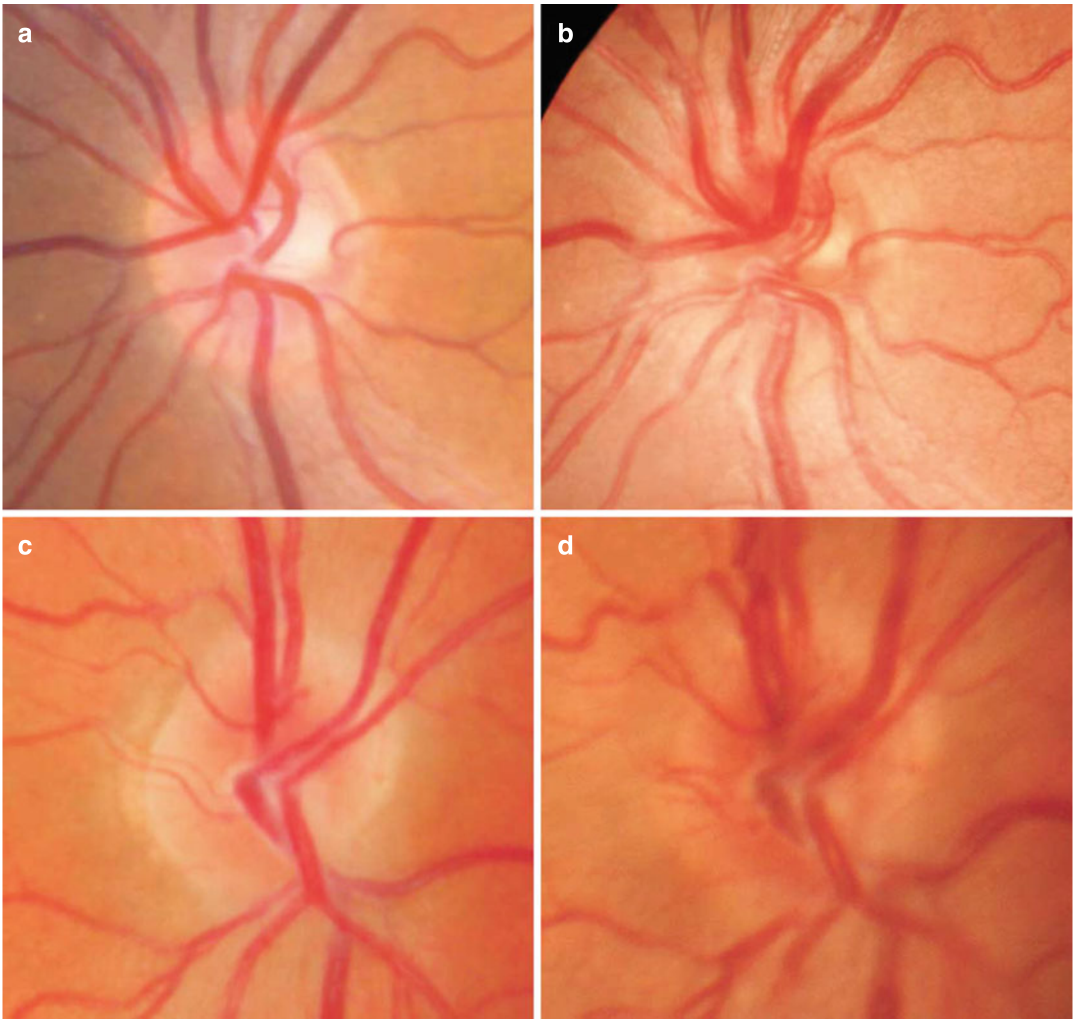

Fig. 5.2 Optic disk swelling. The left optic disk of climber 9 (group 1) appears normal at baseline examination (490 m), 1 month before the expedition (**a**), and swollen at camp 2 (6265 m) (**b**). Similar changes are seen in the right optic disk of climber 5 (group 2) at baseline examination, 1 month before the expedition (**c**), and at camp 3 (6865 m) (**d**)

5.3 Trekking-Related Ultraviolet Exposure

5.3.1 Acute Irradiation

5.3.1.1 Photokeratitis/Ultraviolet Keratitis

The cornea absorbs most ultraviolet radiation, which can cumulatively damage the corneal epithelium, the outermost layer of the cornea. Unprotected exposure to sun rays at high altitudes, often on highly reflective snow fields, most often leads to direct corneal epithelial injury, also known as "snow blindness." The keratitis-effective irradiance seems to depend on altitude, characteristics of the ozone layer, and the reflectivity of the earth's surface at time of exposure [31].

This ultraviolet keratitis is a self-limited inflammatory disorder of the cornea. Symptoms include excruciating pain, decreased visual acuity, foreign body sensation, burning, and tearing with a red eye. These symptoms commence about 6–12 h after extensive exposure to UV rays and will typically resolve within 72 h [32]. Clinically, a superficial punctate keratitis, usually bilateral, develops primarily. The more severe the case, the greater the damage sustained to cell adhesion, leading to epithelial defects which can progress to total abrasion of the corneal epithelium. Epiphora, conjunctival chemosis, and blepharospasm, impeding a thorough ophthalmic examination, usually also occur.

Treatment To our knowledge, no prospective studies have reported on the treatment of photokeratitis. Common treatment modalities include topical anti-inflammatory drugs, cycloplegics, preservative-free lubricants, bandage contact lenses, and systemic analgesics. Long-term damage to the cornea is rare [31].

Prevention The mainstay of handling snow blindness is prevention by wearing sunglasses which provide adequate protection, preferably with side shields, if at risk of exposure to UV rays.

5.3.2 Chronic Irradiation

Pinguecula, pterygia, cataract, age-related macular degeneration, and ocular surface squamous cell neoplasia/carcinoma are discussed in the paragraph on surfing.

Climatic droplet keratopathy, also known as spheroidal degeneration or Labrador keratopathy, has been strongly linked to actinic damage. The anterior cornea or conjunctiva is primarily affected. Slit-lamp examination shows a range from fine, subepithelial opacities without an effect on visual acuity, to axial corneal scarring and strongly decreased visual acuity [33].

5.4 Surfing

Surfboard riding, known as surfing, is an increasingly popular extreme water sport. Surfing is a complex activity as it relies on a surfer's tactical, cognitive, psychological, technical, biomechanical, and physiological abilities [34].

Surfing originated centuries ago in the South Pacific where it was a central part of Polynesian and then Hawaiian culture. Joseph Banks is thought to have first described surfing in 1779 while on the HMS Endeavour during Captain James Cook's third voyage (http://www.surfingforlife.com/history.html). Modern surfing as a sport, hobby, and recreation emerged in the early twentieth century. Since then, it has increased in popularity, with the number of surfers increasing each year [35], and it is currently practiced in many countries throughout the world. The International Surfing Association has estimated that there are around 23 million surfers worldwide (http://www.statisticbrain.com/surfing-statistics/).

A variety of surfboard designs exist; however, all surfboards have a pointed nose (tip), tail (back end), one to three fins, and an ankle leash. The board design used by each surfer will depend on their experience and wave conditions. "Shortboards" (around 1.83–2.13 m (6–7 feet) long) are typically preferred by experienced surfers as they are easy to maneuver, particularly in large waves, whereas "longboards" (2.44–3.04 m (8–10 feet) long) provide better stability and are therefore preferred by beginners and in smaller waves [36]. The surfboard is typically attached to the surfer's ankle via an elasticized cord known as the "leash," keeping the board with the surfer after a fall. The leash is typically 7–8 feet (2.1–2.4 m) long but can stretch to twice its length. The length of the leash is generally proportional to the length of the board. To prevent the surfer from slipping, the board is either rubbed with sticky wax or has nonskid pads [37].

Acute and chronic conditions have been associated with surfing in both adults [35] and children [38]. Acute trauma is most common, with lacerations, contusions, sprains, and fractures reported [35, 36], including injuries to the eye and orbit [39]. Environmental exposure, such as to ultraviolet light and salt water, is mainly responsible for chronic conditions [35]. Acutely painful ultraviolet keratitis can also affect the surfer.

5.5 Surfing-Related Ocular Trauma

Surfing-related ocular trauma can impact both the eye and the orbit. It is thought to occur infrequently but has the potential for significant morbidity. Of all eye trauma, sports-related injuries form a small proportion but have a significant morbidity [40]. The head and neck are common sites for surfing-related trauma, though fortunately major ocular or orbital trauma are infrequent [41, 42].

5.5.1 Epidemiology

There is limited data available on the worldwide epidemiology of surfing-related injuries [37]. Most studies conducted have included small numbers of patients and have been limited to a set geographical location [37]. In a cross-sectional survey of surfers at 8 Victorian beaches in Australia over 12 months, with 646 surfers enrolled (90 % male; median age, 27 years; median years surfing, 10), 145 surfers reported a significant acute injury in the 12 months prior to the survey in 2003 (0.26 injuries/surfer/year) [43]. A study of 346 surfers in Victoria published in 1983 reported an injury rate of 3.5 moderate and severe injuries per 1,000 surfing days. However, this data may overestimate the injury rate due to reporting bias as the studies were survey based [36]. For competitive surfing, a rate of 13 acute injuries per 1,000 h has been reported [42].

Overall, most studies have found being hit by a surfboard to be the most common cause of surfing-related injury [36, 37, 42–44]. For example, Taylor et al. reported striking a surfboard or another surfer (45 %), "wiping out" (36 %), and striking the seabed (18 %) as the most common causes of acute injuries [43]. In another survey study of the lacerations to the head, 15 % were to the eyebrow [36]. Three severe injuries were reported to have occurred in California in the winter months after the surfers "wiped out" when trying to ride a large wave or avoid an oncoming wave [45]. Head and leg injuries have been reported most commonly with surfing [36, 37], except in competitive surfers where knee sprains/strains occurred most frequently [42].

Data is also lacking on the epidemiology of ocular and orbital trauma due to surfing. In the literature, there have been more reports of surfing-related ocular injuries in males [46], but this is probably due to the fact that there are many more male than female surfers. Of all eye trauma, sports-related injuries form a small proportion but have a significant morbidity [40] and form a significant proportion of enucleations [47].

Eye injuries in surfing are mainly due to blunt trauma from direct high-energy collision with the tip of the surfboard [48], and the most common injuries include lacerations and soft-tissue injuries [36, 37]. When the energy is dissipated into the orbit, burst lacerations occur with disruption of ocular tissues, global rupture, and orbital fractures [41].

Over time, boards have become smaller and lighter with a sharp nose, tail, and skeg; leashes have been elasticized and surfing breaks have become more crowded [36]. It has been postulated that these factors may have resulted in an increase in head/face injuries, since shorter and lighter boards are more likely to be thrown around in the surf [39, 41], with the elasticized leash "snapping" the board back toward the surfer with considerable force and energy [37].

5.5.2 Mechanism and Clinical Features

Injury typically results from direct trauma by the surfer's own surfboard [36, 37, 46]; impact with rocks or other surfers' boards are less frequently responsible [36]. Injury most commonly results from impact with a sharp part of the surfboard such as the nose, fin, or tail [36, 45, 46] at high velocity following a fall [46]. The nose is most frequently involved as it is small enough to fit into the bony orbit [37, 46]. Trauma occurs when the energy from collision with the board is dissipated into the orbit; this disrupts ocular tissues and can produce global rupture and orbital fractures [41].

The introduction of leashes in surfing has been implicated in ocular injury [45]. The leash connects the surfer's ankle to the base of the surfboard, preventing it from being lost following a fall. However, after a fall, the leash allows the surfboard—which can travel at great speed and have significant mass—to be snapped back at the surfer with great force and energy transmitted from the broken wave [37, 46]. The length of the leash can vary, and although a short leash has the advantage of keeping the surfboard close to the surfer, it may also place the surfer at greater risk [36]. In one series of surfing-related ocular injuries, all surfers were using short leashes [45]. In another, leashes were found to be responsible for 9 % of all injuries reported [36]. Notably, however, leashes can prevent injuries from loose boards and act as a floatation device in the case of severe injury [36].

Retained foreign bodies, although less common, have also been reported with surfing-related trauma and are thought to occur due to impact at high velocity [46]. This is similar to other sports with high-velocity impact, such as water skiing [46]. Notably, most modern surfboards are constructed with a light polyurethane foam core reinforced by a rigid fiberglass (silicon dioxide, various metals, and elements) and resin skin [37, 41]. These are covered by a fabric made by forcing molten glass through a sieve, which is then spun into threads and woven in sheets [41]. One study reported the case of an orbital foreign body due to retained fiberglass following a high-energy surfing trauma [41], while another reported a foreign body pseudotumor ("surfinoma") in association with a retained piece of fiberglass from a surfboard [48].

5.5.3 Morbidity

Surfing-related eye injuries have a high ocular morbidity, with many resulting in permanent visual loss [45, 46]. In one study, retinal specialists in three states of the USA (California, Florida, and Hawaii) reported 11 injuries, with only two patients regaining their pre-injury vision. Five of these patients had a final vision of hand movements or worse [46]. The poor outcomes were due to a high rate of posterior segment trauma and globe rupture [46]. Given that young males entering their productive years are the most commonly affected, visual disability can have a significant psychosocial impact [46].

5.5.4 Management of Surfing-Related Ocular Trauma

Surfing-related ocular trauma should be managed according to principles of trauma management. This means that general trauma management should be provided prior to attending to the eye—control of bleeding, consideration of neck injury, immobilization of injured areas, and close monitoring for life-threatening emergencies, such as a cervical facture or splenic rupture [39]. Tetanus status should be determined and prophylaxis given as appropriate.

Ocular and orbital management will then depend on the severity of the injury and the particular ocular, orbital, and/or periorbital structures involved. Ocular and skin "aquatic" wounds should be irrigated with balanced salt solution and normal saline (0.9 % sodium chloride) [49], respectively, to reduce the risk of infection. If required, debridement is then performed to remove foreign bodies and/or devitalized tissue. As surfing-related trauma occurs in an aquatic environment, the water may be contaminated with bacteria and sediment. This should be followed by primary repair of a globe rupture or skin lacerations as soon as possible. However, if an injury is not debilitating, a surfer may continue to surf and delay their presentation for days [39], and secondary repair may be needed in some cases. Following globe rupture, retinal review is required due to the risk of vision-threatening posterior segment complications [46].

The literature reports cases of bacteria isolated from surfers wounds, including *Staphylococcus albus*, *Staphylococcus aureus* (coagulase-positive), *Escherichia coli*, and beta-hemolytic *Streptococcus pyogenes* (group A) [50]. The possibility of infection should therefore be considered, skin wounds should be cleaned, and broad spectrum antibiotic coverage given. If infection does occur, it may become chronic and be associated with soft tissue inflammation [51, 52]. Notably, some surf breaks may be located close to sewerage outlets. For ocular injury, close monitoring for endophthalmitis is essential.

Following an injury, the surfer should be strictly advised when they can return to surfing; surfers are notoriously keen to return to surfing and may do so before being advised [39].

5.6 Prevention of Surfing-Related Ocular Trauma

Prevention is a key part of the management of surfing-related ocular trauma, as injuries can have a high morbidity despite treatment once they have occurred [46]. Although board modifications and safety equipment can prevent injuries, they may alter the performance, look, and image of the board or surfer [37]; given that surfing is associated with a carefree attitude, the introduction of such preventative measures can be difficult [41]. In competitive surfing, mandatory use of modified boards and safety equipment may help their adoption on a wider scale [37]. Research to firmly establish the benefits of safety measures would also be beneficial [53].

5.6.1 Board Modifications

As the nose of the board, in particular, is responsible for most injuries, blunting or fitting a protective guard over this part can reduce injury [36, 37, 46], making the nose wider than the average human orbit—a width of 40 mm and a height of 35 mm [46]. In Australia, standards for nose shape now exist for surfboard manufacturers [54], as simple modifications to surfboard design have the potential to save sight.

Similarly, duller, softer, flexible, or breakable fins can be used [37, 46]. Despite these measures, it may not be possible to prevent injury altogether, as the surfboard can still impact the surfer, especially when tethered via the leash [35]. With the leash unlikely to be removed due to its benefits [36], longer ankle leashes may reduce the tendency for boards to snap back due to the tension created on the leash when the surfer rises to the surface [45]. There is also a limit to the degree of board modification that may be accepted by the surfer if these affect the performance or look of the board [35, 53].

5.6.2 Safety Equipment

Given the limitations on board modification discussed above, safety equipment such as protective glasses and helmets play an important role in the prevention of surfing-related trauma. However, such equipment is often not used due to concerns as to their effects on performance and image [37], as they are not considered consistent with the “carefree” attitude of a surfer [45]. Traditional protective eyewear has also been associated with fogging and reduced vision [46].

Protective eyewear designed for other water sports has been recommended to prevent surfing-related ocular trauma, as well as protecting the eyes from UV damage. A variety of eyewear is available to the surfer [45], which varies significantly in terms of fit and capacity to protect the eye from injury.

The importance of protective eyewear for children’s sports has been recently recognized by the American Academy of Pediatrics and the American Academy of Ophthalmology. In a joint statement, although surfing is not specifically mentioned, they recommend protective eyewear for all children participating in sports with a risk of injury. For those who are functionally one-eyed and following eye surgery to trauma, such eyewear should be mandatory (http://www.aao.org/about/policy/upload/Protective-Eyewear-for-Young-Athletes.pdf). It is also possible for surfers who wear prescription glasses to have their refractive error incorporated into protective eyewear.

Protective head gear has been recommended for surfers due to the occurrence of face/head injuries [37, 41]. Although evidence is lacking as to their efficacy [41], it is not unreasonable to assume that they would provide some protection against a surfboard. Helmets have also been designed with retractable, shatterproof visors for eye protection.

5.6.3 Conclusions

Although overall injuries from surfing are less common than in other sports [36], injuries to the eye are common and often serious among surfers, and effective treatment and preventative strategies can minimize the risk of injury and disease. Increasing public awareness and demand may make safer surfboard designs routinely available to all surfers [46].

5.7 Surfing-Related Ultraviolet Exposure

Surfing is an outdoor activity that surfers typically undertake for hours at a time. The surfer is therefore exposed to potentially significant levels of UV irradiation, both directly from the sun and reflected off the water.

5.7.1 The Effects of Ultraviolet Light Exposure

Ultraviolet light (UV, 260–400 nm) exposure can have acute and chronic effects on the eye and periorbital structures. Evidence is strong that the formation of eyelid malignancies such as basal cell and squamous cell carcinoma, but also benign changes such as photokeratitis, climatic droplet keratopathy, pterygium, and cortical cataracts, is associated with UV exposure [55]. However, evidence for the relation of pinguecula, ocular surface squamous neoplasia (OSSN), ocular melanoma, and nuclear and posterior subcapsular cataracts to UV exposure is weaker. During surfing, the eye is exposed to direct UV rays from sunlight and to that reflected from the water's surface [22].

5.7.2 Acute UV Exposure

5.7.2.1 Ultraviolet Keratitis

Acutely intense UV exposure, such as that which can occur after long periods of surfing, can result in painful keratitis [22], discussed in Chap. 10 (high-altitude trekking). This condition is painful but self-limiting, and treatment is directed toward pain relief.

5.7.3 Chronic UV Exposure

Chronic exposure to ultraviolet light and salt water can affect the ocular surface; increased rates of pinguecula, pterygia, and ocular surface squamous neoplasia are discussed below. Climatic droplet keratopathy, cataracts, and melanoma have also been associated with UV exposure [55, 56].

5.7.3.1 Pinguecula and Pterygia

A pingueculum appears as a pale, yellow lesion adjacent to the limbus, on either side of the cornea in the palpebral fissure. Histologically, it is composed of degenerative collagen. These lesions are common, usually bilateral and asymptomatic. Pingueculae rarely cause significant problems and therefore do not typically require treatment. However, they may occasionally become inflamed and require therapy with topical lubricants and/or steroids and can progress to pterygia.

Pterygia are wing-shaped growths on the cornea. They are thought to arise from pinguecula and have been reported to occur frequently in surfers [37]. Histologically, a pannus is seen invading Bowman's membrane. This fibrovascular tissue can potentially interfere with vision directly, if they grow to involve the pupillary area, or indirectly by inducing significant corneal astigmatism [57]. The underlying pathophysiological mechanism is thought to be UV light exposure [55]. For the surfer, drying by the wind and exposure to salt water are also thought to contribute [58].

5.7.3.2 Ocular Surface Squamous Neoplasia

Exposure to solar UV over a lifetime has been associated with increased risk of ocular epithelial dysplasias [59] and has been suggested as a risk factor for squamous cell carcinoma of the conjunctiva [60]. Squamous cell carcinoma of the conjunctiva is rare, but it has been reported in association with necrotizing scleritis in an otherwise healthy 31-year-old white Australian male surfer [61].

5.7.3.3 Eyelid Carcinoma

Ultraviolet exposure has been directly linked to eyelid malignancy, with the most common malignant tumors being basal cell carcinoma (BCC) and squamous cell carcinoma (SCC) [55].

5.7.3.4 Age-Related Macular Degeneration

Sunlight exposure has also been associated with age-related macular degeneration (ARMD) [62, 63]. Current evidence implies that ARMD is not a sequelae of UV exposure but a consequence of irradiation by components of visible light, especially the blue light fraction (peak wavelength: 465 nm) [64, 65]. It is possible that surfers and high-altitude trekkers may be at increased risk for these conditions due to higher exposure rates [39]. However, no current studies have established if ARMD is more common in surfers or high-altitude mountaineers.

5.7.3.5 Prevention of UV-Related Ocular and Periocular Conditions

UV exposure to the eye and eyelids can be reduced by wearing sunglasses. Brims on wetsuit hoods, a visor or hat strapped behind goggles [39], and use of swimming goggles with a UV filter [39] can also reduce UV exposure to the surfer.

5.8 Aquatic Conditions Affecting Surfers

Surfing is done in salt-or freshwater, where plants, microbes, and marine animals are present, all of which can produce allergic reactions, infections, trauma, and envenomations in the surfer [66], which may affect the eye or the skin [52, 67, 68].

Acanthamoeba is a protozoan, ubiquitous in water, air, soil, and dust, which can infect the cornea, the window of the eyes [69]. Infections with acanthamoeba can become chronic, in some cases difficult to treat, resulting in loss of vision or of the eye itself [69]. Swimming while wearing contact lenses and exposure to contaminated water are risk factors for infection [70]. Acanthamoeba keratitis has been reported following windsurfing [71]; therefore, surfers are likely to be at risk of corneal infection with acanthamoeba.

A variety of surfing-related skin conditions have been described, many associated with infection by organisms including bacteria, mycoplasma, parasites, and yeast [66]. For example, the phytoplankton dermatoses include diseases caused by algae, cyanobacteria, and dinoflagellates [66].

The surfer is also at risk of stings from jellyfish and stingrays [72], which may produce a skin reaction known as "seabathers eruption" or rarely be fatal [35, 52]. Coral reefs can also injure the surfer.

References

1. Houston CS. High altitude illness: disease with protean manifestations. JAMA. 1976;236(19):2193–5.
2. Meehan RT, Zavala DC. The pathophysiology of acute high-altitude illness. Am J Med. 1982;73(3):395–403.
3. Hackett PH, Roach RC. High-altitude illness. N Engl J Med. 2001;345(2):107–14.
4. Schneider M, Bernasch D, Weymann J, Holle R, Bartsch P. Acute mountain sickness: influence of susceptibility, preexposure, and ascent rate. Med Sci Sports Exerc. 2002;34(12):1886–91.
5. Turk AJ, Maggiorini M, Hess T, Merz T, Bosch MM, Barthelmes D, Hefti U, Pichler J, Senn O, Schoch OD. Effect of ascent protocol on acute mountain sickness and success at Muztagh Ata, 7546m. Bloch KE1. High Alt Med Biol. 2009. Hypoxia. 10(1):25–32.
6. Bosch MM, Barthelmes D, Merz TM, Knecht PB, Truffer F, Bloch KE, et al. New insights into changes in corneal thickness in healthy mountaineers during a very-high-altitude climb to Mount Muztagh Ata. Arch Ophthalmol. 2010;128(2):184–9.
7. Flynn WJ, Miller 2nd RE, Tredici TJ, Block MG. Soft contact lens wear at altitude: effects of hypoxia. Aviat Space Environ Med. 1988;59(1):44–8.
8. Bosch MM, Barthelmes D, Merz TM, Truffer F, Knecht PB, Petrig B, et al. Intraocular pressure during a very high altitude climb. Invest Ophthalmol Vis Sci. 2010;51(3):1609–13.

9. Mader TH, Blanton CL, Gilbert BN, Kubis KC, Schallhorn SC, White LJ, et al. Refractive changes during 72-hour exposure to high altitude after refractive surgery. Ophthalmology. 1996;103(8):1188–95.
10. White LJ, Mader TH. Refractive changes with increasing altitude after radial keratotomy. Am J Ophthalmol. 1993;115(6):821–3.
11. Boes DA, Omura AK, Hennessy MJ. Effect of high-altitude exposure on myopic laser in situ keratomileusis. J Cataract Refract Surg. 2001;27(12):1937–41.
12. Nelson ML, Brady S, Mader TH, White LJ, Parmley VC, Winkle RK. Refractive changes caused by hypoxia after laser in situ keratomileusis surgery. Ophthalmology. 2001;108(3):542–4.
13. Hackett PH, Rennie D. Rales, peripheral edema, retinal hemorrhage and acute mountain sickness. Am J Med. 1979;67(2):214–8.
14. Honigman B, Noordewier E, Kleinman D, Yaron M. High altitude retinal hemorrhages in a Colorado skier. High Alt Med Biol. 2001;2(4):539–44.
15. Wiedman M. High altitude retinal hemorrhage. Arch Ophthalmol. 1975;93(6):401–3.
16. Barthelmes D, Bosch MM, Merz TM, Petrig BL, Truffer F, Bloch KE, et al. Delayed appearance of high altitude retinal hemorrhages. PLoS One. 2011;6(2):e11532.
17. McFadden DM, Houston CS, Sutton JR, Powles AC, Gray GW, Roberts RS. High altitude retinopathy. JAMA. 1981;245(6):581–6.
18. Brinchmann-Hansen O, Myhre K, Sandvik L. Retinal vessel responses to exercise and hypoxia before and after high altitude acclimatisation. Eye. 1989; 3(Pt 6):768–76.
19. Arora R, Jha KN, Sathian B. Retinal changes in various altitude illnesses. Singapore Med J. 2011;52(9):685–8.
20. Willmann G, Fischer MD, Schatz A, Schommer K, Messias A, Zrenner E, et al. Quantification of optic disc edema during exposure to high altitude shows no correlation to acute mountain sickness. PLoS One. 2011;6(11):27022.
21. Frayser R, Houston CS, Bryan AC, Rennie ID, Gray G. Retinal hemorrhage at high altitude. N Engl J Med. 1970;282(21):1183–4.
22. Rennie D, Morrissey J. Retinal changes in Himalayan climbers. Arch Ophthalmol. 1975;93(6):395–400.
23. Shults WT, Swan KC. High altitude retinopathy in mountain climbers. Arch Ophthalmol. 1975;93(6):404–8.
24. Butler FK, Harris Jr DJ, Reynolds RD. Altitude retinopathy on Mount Everest, 1989. Ophthalmology. 1992;99(5):739–46.
25. Duane TD, Osher RH, Green WR. White centered hemorrhages: their significance. Ophthalmology. 1980;87(1):66–9.
26. Roth M. Über Netzhautaffectionen bei Wundfiebern. I. Die embolische Panophthalmitis. Deutsche Zeitschrift für Chirurgie. 1872;1:471–84.
27. Rodriguez-Adrian LJ, King RT, Tamayo-Derat LG, Miller JW, Garcia CA, Rex JH. Retinal lesions as clues to disseminated bacterial and candidal infections: frequency, natural history, and etiology. Medicine (Baltimore). 2003;82(3):187–202.
28. Wechsler DZ, Tay TS, McKay DL. Life-threatening haematological disorders presenting with ophthalmic manifestations. Clin Experiment Ophthalmol. 2004;32(5):547–50.
29. Bosch MM, Barthelmes D, Landau K. High altitude retinal hemorrhages–an update. High Alt Med Biol. 2012;13(4):240–4.
30. Bosch MM, Barthelmes D, Merz T, Bloch KE, Turk AJ, Hefti U, et al. High incidence of optic disc swelling at very high altitudes. Arch Ophthalmol. 2008;126(5):1–7.
31. Blumthaler M, Ambach W, Daxecker F. On the threshold radiant exposure for keratitis solaris. Invest Ophthalmol Vis Sci. 1987;28(10):1713–6.
32. Schein OD. Phototoxicity and the cornea. J Natl Med Assoc. 1992;84(7):579–83.
33. Fraunfelder FT, Hanna C. Spherodial degeneration of cornea and conjunctiva. 3. Incidences, classification, and etiology. Am J Ophthalmol. 1973;76(1):41–50.
34. Mendez-Villanueva A, Bishop D. Physiological aspects of surfboard riding performance. Sports Med. 2005;35(1):55–70.
35. Taylor KS, Zoltan TB, Achar SA. Medical illnesses and injuries encountered during surfing. Curr Sports Med Rep. 2006;5(5):262–7.
36. Lowdon BJ, Pateman NA, Pitman AJ. Surfboard-riding injuries. Med J Aust. 1983;2(12):613–6.
37. Nathanson A, Haynes P, Galanis D. Surfing injuries. Am J Emerg Med. 2002;20(3):155–60.
38. Moran K, Webber J. Leisure-related injuries at the beach: an analysis of lifeguard incident report forms in New Zealand, 2007–12. Int J Inj Contr Saf Promot. 2014;21(1):68–74.
39. Renneker M. Medical aspects of surfing. Phys Sportsmed. 1987;15(12):96–105.
40. Schein OD, Hibberd PL, Shingleton BJ, Kunzweiler T, Frambach DA, Seddon JM, et al. The spectrum and burden of ocular injury. Ophthalmology. 1988; 95(3):300–5.
41. Hall G, Benger RS. Missed diagnosis of an intraorbital foreign body of surfboard origin. Ophthal Plast Reconstr Surg. 2004;20(3):250–2.
42. Nathanson A, Bird S, Dao L, Tam-Sing K. Competitive surfing injuries: a prospective study of surfing-related injuries among contest surfers. Am J Sports Med. 2007;35(1):113–7.
43. Taylor DM, Bennett D, Carter M, Garewal D, Finch CF. Acute injury and chronic disability resulting from surfboard riding. J Sci Med Sport. 2004;7(4):429–37.
44. Grenfell RD. Beach-related injuries. Med J Aust. 1997;166(7):390.
45. Zoumalan CI, Blumenkranz MS, McCulley TJ, Moshfeghi DM. Severe surfing-related ocular injuries: the Stanford Northern Californian experience. Br J Sports Med. 2008;42(10):855–7.
46. Kim JW, McDonald HR, Rubsamen PE, Luttrull JK, Drouilhet JH, Frambach DA, et al. Surfing-related ocular injuries. Retina. 1998;18(5):424–9.

47. Fountain TR, Albert DM. The histopathology of sports-related ocular trauma, 1980–1986. Int Ophthalmol Clin. 1988;28(3):206–10.
48. Squire T, Sherlock M, Wilson P, Tan B, Hope N, Anderson SE. Surfinoma: a case report on a pseudotumor developing after a surfing sports injury. Skeletal Radiol. 2010;39(12):1239–43.
49. Angeras MH, Brandberg A, Falk A, Seeman T. Comparison between sterile saline and tap water for the cleaning of acute traumatic soft tissue wounds. Eur J Surg. 1992;158(6–7):347–50.
50. Erickson JG, von Gemmingen GR. Surfer's nodules and other complications of surfboarding. JAMA. 1967;201(2):134–6.
51. Bailey Jr JP, Stevens SJ, Bell WM, Mealing Jr HG, Loebl DH, Cook EH. Mycobacterium marinum infection. A fishy story. JAMA. 1982;247(9):13–4.
52. Bailey PM, Little M, Jelinek GA, Wilce JA. Jellyfish envenoming syndromes: unknown toxic mechanisms and unproven therapies. Med J Aust. 2003; 178(1):34–7.
53. McDonald TD. Perceptions of surfboard riders regarding the need for protective headgear. Wilderness Environ Med. 2005;16(2):75–80.
54. Starr K, Geoff B, Renneker M. Sick surfers ask the surf docs and Dr Geoff. Palo Alto: Bull Publishing Co; 1993.
55. Yam JC, Kwok AK. Ultraviolet light and ocular diseases. Int Ophthalmol. 2014;34(2):383–400.
56. Moran DJ, Hollows FC. Pterygium and ultraviolet radiation: a positive correlation. Br J Ophthalmol. 1984;68(5):343–6.
57. Kheirkhah A, Safi H, Molaei S, Nazari R, Behrouz MJ, Raju VK. Effects of pterygium surgery on front and back corneal astigmatism. Can J Ophtalmol. 2012;47(5):423–8.
58. Taylor HR. Aetiology of climatic droplet keratopathy and pterygium. Br J Ophthalmol. 1980;64(3):154–63.
59. Lee GA, Williams G, Hirst LW, Green AC. Risk factors in the development of ocular surface epithelial dysplasia. Ophthalmology. 1994;101(2):360–4.
60. Sun EC, Fears TR, Goedert JJ. Epidemiology of squamous cell conjunctival cancer. Cancer Epidemiol Biomark Prev Publ Am Assoc Can Res Am Soc Prev Oncol. 1997;6(2):73–7.
61. Younan N, McClellan K. Squamous cell carcinoma with necrotizing scleritis. Aust N Z J Ophthalmol. 1999;27(2):149–51.
62. Grimm C, Wenzel A, Hafezi F, Yu S, Redmond TM, Reme CE. Protection of Rpe65- deficient mice identifies rhodopsin as a mediator of light-induced retinal degeneration. Nat Genet. 2000;25(1):63–6.
63. Taylor HR, Munoz B, West S, Bressler NM, Bressler SB, Rosenthal FS. Visible light and risk of age-related macular degeneration. Trans Am Ophthalmol Soc. 1990;88:163–73; discussion: 73–8.
64. Grimm C, Wenzel A, Williams T, Rol P, Hafezi F, Reme C. Rhodopsin-mediated blue light damage to the rat retina: effect of photoreversal of bleaching. Invest Ophthalmol Vis Sci. 2001;42(2):497–505.
65. Nilsson SE, Sundelin SP, Wihlmark U, Brunk UT. Aging of cultured retinal pigment epithelial cells: oxidative reactions, lipofuscin formation and blue light damage. Doc Ophthalmol. 2003;106(1):13–6.
66. Maeyens E, Jr. Aquatic skin disorders. In: Wilderness medicine. Mosby: Philadelphia; 2011. p. 82.
67. Tlougan BE, Podjasek JO, Adams BB. Aquatic sports dermatoses: part 3. On the water. Int J Dermatol. 2010;49(10):1111–20.
68. Bischof RO. Surf rider's dermatitis. Contact Dermatitis. 1995;32(4):247.
69. Dart JK, Saw VP, Kilvington S. Acanthamoeba keratitis: diagnosis and treatment update 2009. Am J Ophthalmol. 2009;148(4):487–99.
70. Radford CF, Minassian DC, Dart JK. Acanthamoeba keratitis in England and Wales: incidence, outcome, and risk factors. Br J Ophthalmol. 2002;86(5):536–42.
71. Bos HJ, Volker-Dieben HJ, Kok-van Alphen CC. A case of Acanthamoeba keratitis in the Netherlands. Trans R Soc Trop Med Hyg. 1981;75(1):86–91.
72. Allen RH, Eiseman B, Straehley CJ, Orloff BG. Surfing injuries At waikiki. JAMA. 1977;237(7):668–70.

6 Extreme Sports Dermatology

Brian B. Adams

6.1 Traumatic Conditions

Extreme athletes exercise at the margin of activity and as such experience intense physical forces inflicted by their sporting environment. The skin represents the first and foremost barrier between the athlete and this unforgiving environment.

6.1.1 Friction Bullae

Perhaps the most common of the skin conditions of the extreme athlete is bullae. Friction bullae result from the rapid cycling of one's skin over the athlete's equipment. Several factors increase the likelihood that an athlete will develop friction bullae. Heat, moisture, ill-fitted shoewear, and abrasive clothing all serve to increase the chance that an athlete will acquire a blister (Fig. 6.1).

These bullae, which result from splits in the epidermis at the level of the stratum granulosum, occur most frequently on the feet and hands, but can occur at any site wherein the skin becomes rubbed repeatedly. Once a split in the epidermis develops, the space fills with fluid and a tense blister forms. These bullae can cause discomfort and may hinder further activity [1].

While the diagnosis is often straightforward, the management and prevention of these lesions present challenges. Research reveals that a blister, which is repeatedly lanced and drained three times in 1 day, heals more rapidly and less likely develops secondary infection [2]. The clinician should lance the blister in a focal spot and take great care to keep the blister roof intact. No commercially available dressing possesses the ideal coverage of the wound base as well as the athlete's own skin.

Once lanced, the athlete should apply petroleum jelly and cover the area with an adherent dressing. Only rarely do these blisters become infected and require topical or oral antibiotics. Athletes can prevent bullae by essentially

Fig. 6.1 Friction bullae frequently occur on the heel

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decreasing the friction between their skin and the sporting environment.

Simply wearing synthetic moisture-wicking clothing keeps the skin relatively dry and cool and minimizes the production of bullae. Athletes who are particularly prone to blisters may need to wear protective gloves or double layer of socks. Applying petroleum jelly to areas of the skin prior to athletic activity further minimizes the bullae production. Athletes must also ensure that their footwear fits well as ill-fitting equipment produces loose or tight spots that create friction bullae [1].

6.1.2 Athlete's Toenail

Extreme athletes' nails experience enormous pressure and tension as a result of their activities. Abrupt and intense forces can completely remove a finger or toenail. More commonly, athletes develop nail changes related to chronic, low-grade pressure, and tugging. The changes related to these physical forces include longitudinal and transverse ridging, onycholysis (separation of the nail plate from the nail bed), discoloration around the periungual area, and calluses periungually (Fig. 6.2) [1, 3].

Extreme athletes must employ several techniques to prevent athlete's nail. All nails should be closely cut in a straight-across fashion that allows an equal distribution of the force created during the athlete's physical activity. Cutting nails in a curved manner places increase pressure on the middle portion of the nail. As the sport allows, wearing gloves also helps to reduce the friction and pressure experienced by fingernails. Extreme athletes need to ensure that their footwear has an adequate toe box [1]. Unique lacing techniques can also redistribute the physical forces away from the toenails and onto the ankle which is better suited to experience the forces that create long-term nail changes. To employ this lacing method, the athlete undoes both laces from the last eyelet; instead of crossing the lace into the opposite side's eyelet, one enters the eyelet on the same side such that two loops are generated. The free lace ends then are crossed and thread through the opposite loop. Then the athlete can tie the ends as usual [4].

6.1.3 Talon Noire

The significance of talon noire resides in the fact that this condition can confuse the clinician to believe that the athlete has warts or melanoma. Talon noire, otherwise known as black heel, occurs most commonly in younger athletes on the posterior lateral or medial heel (Fig. 6.3) [1]. Caused by friction with subsequent hemorrhage into the skin, talon noire is asymptomatic and requires no therapy [5].

Fig. 6.2 Athlete's nail demonstrates periungual change and transverse ridging and hemorrhage

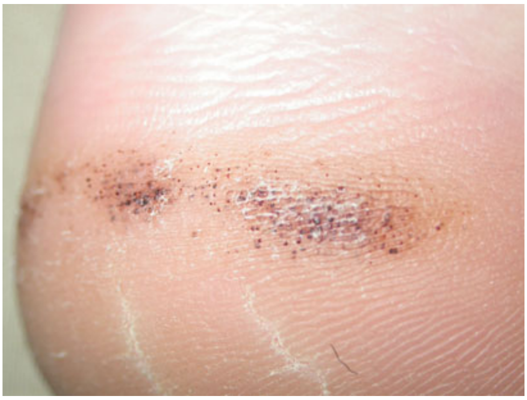

Fig. 6.3 This heel illustrates talon noire which can easily be confused with verruca (warts)

6.1.4 Piezogenic Pedal Papules

In addition to friction, pressure can also create havoc in an extreme athlete's skin. Piezogenic pedal papules primarily affect the feet of young women, and while most often not painful, the discomfort associated with the condition can prevent the endeavors on the extreme athlete. The subcutaneous fat and associated nerves and microvasculature protrude up into the dermis that can cause strangulation and subsequent pain [1]. Clinicians may misdiagnose the foot pain and embark on an extensive musculoskeletal work-up without having the athlete stand on only the affected extremity that then readily reveals the skin colored to yellow papules most often on the sides of the heel. Multiple therapies exist including intralesional steroids [6], compression [7], and acupuncture [8]. Susceptible athletes sometimes find heel pads prevent piezogenic pedal papules.

6.1.5 Athlete's Nodules

A combination of pressure and friction, particularly along the lower extremities, can cause a skin condition called athlete' nodules. Two mechanisms exist by which athletes can develop these lesions. First, surfers get “surfer's knots or nodules” on their legs as a result of pressure, friction, and rough board surface (along with sand) [9]. As surfers paddle out to catch waves (especially those in colder waters), they kneel on the board, and the combination of these factors and forces creates a foreign-body reaction in the skin. Second, these nodules can develop as a reaction to constant pressure in one particular location that most often related to protective equipment or shoewear. As a result, the dermis hypertrophies creating a collagenoma.

Regardless of the exact etiology, the differential diagnosis of these firms, skin colored to erythematous nodules can be vast. Atypical mycobacterial and deep fungal skin infections have this appearance, as do inflammatory conditions such as granuloma annulare and rheumatoid nodules. Primary and secondary malignancies can also share a similar morphology. While a biopsy will differentiate among these various cutaneous ailments, linking the lesion to one's athletic pursuits facilitates early accurate diagnosis.

Athlete's nodules may require excision, while others respond to intralesional steroids. Occasionally changing the equipment or footwear results in clearance. To prevent athlete's nodules, extreme athletes can wear padding between their skin and the offending piece of equipment [10]. In the case of surfer's knots, surfers may lie prone on the board to equally distribute forces along the board. Surfers, in colder waters, may wear a wet suit to comfortably allow a prone position.

6.1.6 Sunburns and Actinic Damage

Extreme athletes experience an enormously high level of ultraviolet radiation (UVR). As a result, these athletes ultimately risk acquiring skin cancer and actinic damage (wrinkles and dyspigmentation) (Figs. 6.4 and 6.5).

Several factors result in this intense UVR exposure. Athletes practice and compete during the time of peak UVR that is between 10 am and 4 pm. Additionally, they train for long periods of time and started this training often early in their life resulting in an immense total lifetime exposure. Sweating, inherent to most extreme

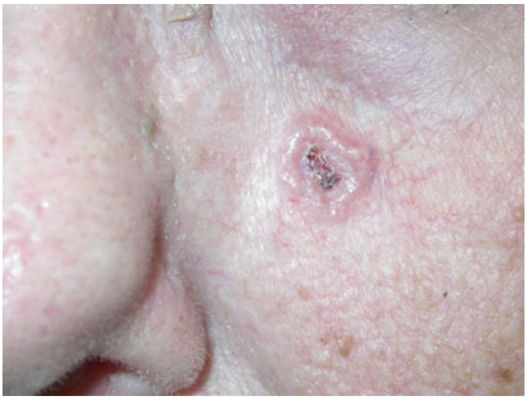

Fig. 6.4 Long-term, extreme athletes risk developing basal cell carcinoma. This photo depicts the characteristic pearly border and telangiectasias

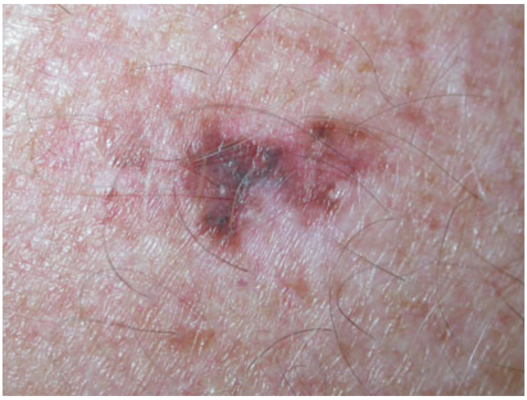

Fig. 6.5 Extreme athletes' skin endures enormous ultraviolet light that ultimately can create malignant melanoma

sports, enhances the potency of the UVR such that it takes 40 % less UVR to burn athletes if they did not sweat [11]. Several extreme sports exist at very high altitudes. At high altitudes, the atmosphere has not had a chance to filter a significant portion of UVR. For example, the UVR experienced high in the mountains is comparable to the UVR affecting an individual at sea level [12]. Lastly, extreme athletes who compete in snow and water environments must also contend with the significant reflection of UVR off the surfaces. Wearing hats that shade the face will provide no protection against UVR reflecting up to the athletes' face from the environment.

To prevent sunburns and long-term actinic damage, athletes must apply water- and sweat-resistant sunscreen and reapply the lotion or spray after practicing or competing. They should take care to apply areas that athletes often forget which include the ears and any part created by hairstyles. If possible, athletes should avoid the peak hours of UVR exposure and practice early morning or evening. Tightly woven and dark clothing provides ideal sunblocking properties. While athletes traditionally prefer light-colored clothing to keep them relatively cool, the myriad commercially available synthetic moisture-wicking clothing allows the athlete to wear a sporting garment with both excellent UVR-blocking capabilities and good cooling qualities [1].

6.1.7 Miliaria Crystallina

Exposure to extraordinary heat and UVR plays a major role in many extreme sports. One relatively rare cutaneous condition that may occur more often in this population is miliaria crystallina. An affected athlete will develop delicate, crystal-like, small vesicles on their skin; unsuspecting clinicians may misdiagnose the lesions as herpes or another skin infection (Fig. 6.6).

Miliaria crystallina, which results from superficial obstruction of the eccrine duct, highlights the fierce heat that challenges the athlete. Wearing moisture-wicking, dark-colored synthetic clothing will assuage some of the affect of the heat [1].

6.1.8 Frostbite

While heat can cause many ailments in an athlete's skin, cold exposure poses its own challenges. Prolonged exposure to cold can cause significant damage to the cutaneous structures. Wind and moisture can exacerbate the issue. An extreme athlete with frostbite will initially complain of pain and develop erythema on the toes and fingers; as the condition progresses, necrosis ensues. To treat frostbite, clinicians should rapidly rewarm the area by dunking in 40 °C water [13]. This treatment should only occur if no chance of subsequent exposure to prolonged cold remains. Rewarming frostbitten skin and subsequently refreezing that skin result in maximal tissue damage. Extreme athletes whose environment includes freezing temperatures must use thermal clothing and gloves and chemical heating packets [1, 13].

6.1.9 Jellyfish Envenomations

While uncommon overall, extreme athletes risk encounters with water creatures that can affect their skin. Water-based extreme athletes may experience painful jellyfish stings from their long tentacles. Once the tentacles contact the skin, nematocysts fire and cause a linear, erythematous,

Fig. 6.6 The tiny blisters of miliaria crystallina are extremely fragile and rupture easily

and edematous eruption. Treatment includes removing the tentacles with tweezers and applying vinegar solution. Athletes and clinicians should avoid applying freshwater that can activate the nematocysts [1]. Extreme athletes who wish to enter seawater with jellyfish should minimize skin exposure by wearing wet suits as their sport allows.

6.2 Allergic Skin Reactions

Among the most common cutaneous ailments in extreme athletes, after traumatic skin events result from allergies. The main categories of allergy include allergic contact dermatitis, exercise-induced anaphylaxis, and urticaria.

6.2.1 Allergic Contact Dermatitis

In their sporting pursuits, extreme athletes can develop allergies to the various pieces of equipment necessary for their activity. Protective equipment commonly causes allergic contact dermatitis. Shin pads may contain urea formaldehyde and helmets may possess epoxy resins. Extreme athletes who contact tape containing formaldehyde resins or analgesic creams containing eucalyptus can also develop contact dermatitis [14]. Injured or pruritic athletes often reach for Benadryl spray which can create an allergic contact dermatitis.

Fig. 6.7 Eruptions with a linear arrangement strongly suggest an allergic contact dermatitis

Sensitized athletes will develop well-defined, erythematous, scaling eruption in a distribution corresponding to the area of equipment contact (Fig. 6.7).

Acute dermatitis will demonstrate small blisters (vesicles), whereas subacute dermatitis will lack vesicles and instead often display more scale and less erythema.

Allergic contact dermatitis responds well to topical steroids. Affected areas on the trunk, extremities, and scalp respond well to potent (class I) topical steroids. Athletes should use caution with topical steroids on the face (especially the eyelids), groin, and axilla. The latter two areas will experience occlusion, which enhance the potency of topical steroids. In this instance, potent topical steroids may more readily cause side effects that include hypopigmentation, skin thinning, erosions, and acquisition of telangiectasias. Sensitive areas such as these require no more than medium-potency topical steroids such as triamcinolone 0.1 % twice daily; low-potency topical steroids such as hydrocortisone 2.5 %

Table 6.1 Cutaneous allergy in athletes

Sports equipment	Offending agent	Location of eruption	Nonallergenic options
Analgesic cream	*Eucalyptus*	Focal	Hot/cold packs
Athletic tape	Formaldehyde resins	Focal	Acrylate tape
Helmets	Epoxy resins	Forehead, scalp	Silicone
Sailing wishbone	Thiorams	Hands	Aluminum
Shin pads	Urea formaldehyde	Shins	Synthetic padding at interface

twice daily most often will be effective. When athletes need to chronically use topical steroids for their dermatitis in the groin, axilla, or face, the clinician should consider using topical pimecrolimus or tacrolimus. These agents do not possess the potential to cause the side effects aforementioned [1].

To help prevent contact dermatitis, susceptible extreme athletes can use silicone helmets (instead of those containing epoxy resins). Placing a moisture-wicking barrier between the protective pads and the skin not only will provide a barrier between the pad and the skin but also will wick away moisture that would otherwise enhance leaching of the offending allergen from the equipment. Allergic athletes may use acrylate tape to help avoid dermatitis (Table 6.1).

6.2.2 Urticaria

Another somewhat common allergic skin reaction in athletes is the general entity of urticaria. Extreme athletes risk developing three types of urticaria: cholinergic, solar, and cold. While each condition culminates in pruritic, edematous, well-defined, effervescent papules and plaques, the etiologies and morphology differ among the three ailments. Cholinergic urticarias present as small wheals and result from an increase in an athlete's core body temperature; runners seem particularly prone. Cold urticaria occurs in athletes participating in winter or cold-water activities, and solar urticaria abruptly occurs (within minutes) after exposure to ultraviolet radiation. The ice cube test confirms the diagnosis of cold urticaria. An ice cube is placed on the athlete's skin, and after removal and the skin warms, a welt develops where the ice cube rested. Phototesting confirms the diagnosis of solar urticarial [1].

The treatment in all cases of urticaria includes scheduled (not as needed) oral antihistamines. While the eruption will likely last more than 24 h, each individual should not. Typical urticaria lesions resolve in a few hours, only to have another wheal develop elsewhere on the skin. Individual lesions that persist longer than 24 h should prompt biopsy and investigation for urticarial vasculitis. Oral histamines also help prevent each type of urticaria in susceptible athlete who should initiate administration before starting their activities [1]. Extreme athletes who develop cold urticaria should minimize exposed skin; likewise, those athletes who suffer from solar urticaria should employ sun safety measures including wearing broadband-blocking (UVA/UVB) SPF 50 sunscreen that resists water rinsing.

6.2.3 Exercise-Induced Anaphylaxis

Athletes of all types risk developing exercise-induced anaphylaxis if they possess the predisposition. For unclear reasons, runners seem particularly prone to develop the condition [15]. The name of the eruption misleads most clinicians as most cases of exercise-induced anaphylaxis create hemodynamic or respiratory collapse. Pruritus dominates as the most common symptom. Prolonged headaches may persist for days after athletic activity [16]. The angioedema of exercise-induced anaphylaxis affects the palms and soles (Table 6.2).

Athletes with vascular or respiratory compromise need rapid attention to stabilize. Affected should take scheduled oral antihistamines. Susceptible extreme athletes should always partici-

Table 6.2 Frequency of symptoms in exercise-induced anaphylaxis

Symptoms	Frequency (%)
Angioedema (palm or sole swelling)	72
Chest tightness	33
Dyspnea (shortness of breath)	50
Gastrointestinal distress	25
Pruritus (itching)	92
Urticaria (wheals)	86

Table 6.3 Risk factors in the development of *staphylococcal* skin infections

Activity	Relative risk of infection
Having adjacent lockers	60
Sharing towels	47
Sharing soap	15
Acquiring turf burns	7.2
Shaving body hair	6.1

pate with at least one other athlete and always carry an epinephrine pen. Two strategies exist to minimize the activation of exercise-induced anaphylaxis. First, avoiding eating immediately before exercising can mitigate attacks, and second, avoiding extreme temperatures (either excessively cold or hot) can likewise halt the onset of exercise-induced anaphylaxis [1, 15]. Lastly susceptible extreme athletes should never wear jewelry on their fingers or toes as the angioedema can create strangulation and cutting the jewelry off is necessary.

6.3 Cutaneous Infections

Extreme athletes also must contend with cutaneous infections that they acquire from the sporting environment. Bacteria, viruses, and fungi most commonly cause these infections.

6.3.1 Bacteria

6.3.1.1 Folliculitis, Impetigo, and Furunculosis

Staphylococcus and, less commonly, *Streptococcus* cause the vast majority of the bacterial infections that occur in extreme athletes. Traditionally the methicillin-sensitive variety of *Staphylococcus* dominated as the primary organism responsible for bacterial skin infections in athletes, but increasingly, the methicillin-resistant *Staphylococcus* aureus (MRSA) variant causes the *staphylococcal* infection [17]. Multiple factors place the extreme athletes at risk to develop *staphylococcal* infections [18–20] (Table 6.3).

The particular location within the skin structure of the infection determines how the eruption appears clinically. When these bacteria infect the superficial portion of the hair follicle, a follicular pustule with surrounding erythema develops; if the infection proceeds deeper into the hair follicle, a deeply erythematous papulonodule may form that represents furunculosis. If the superficial layers of the epidermis are infected, the athlete will demonstrate impetigo that clinically manifests as yellow (honey-colored) crust on an erythematous base [21].

Extreme athletes will acquire these infections either from the sporting environment or from direct skin-to-skin contact with other athletes. Multiple studies have carefully examined the risk factors involved in epidemics of skin infections in athletes. Common activities that risk acquiring the bacteria are sharing equipment, having previously injured skin, and acquiring turf burns. Researchers have also demonstrated high prevalence of MRSA colonization in many of the surfaces in the sporting environment [22]. Athletes themselves may also carry MRSA or MSSA within their nares. One study revealed that up to a quarter of collegiate football and lacrosse players at one school had MRSA in their nares during the season [23].

Once a bacterial infection is suspected, clinicians should confirm the diagnosis with cultures and sensitivities. One study noted that athletes who received empiric antibiotics without sensitivity testing had a 33 times more likely chance of reoccurrence [24]. Mild cases of folliculitis and impetigo often only need topical therapy with mupirocin twice daily for 5–7 days. Athletes with many lesions may require oral antibiotics. Impetigo, folliculitis, or furunculosis caused by MRSA responds to doxycycline, tetracycline, minocycline, or trimethoprim-sulfamethoxazole. The bacterial infections caused by MSSA clear with dicloxacillin or cephalexin. Clinicians also need to lance and drain furuncles [1, 17].

Extreme athletes can reduce the chance of acquiring these infections by decreasing the amount of exposed skin, not sharing equipment, and carefully washing after practice and competitions. Moisture-wicking, synthetic clothing with UPF (sun protection factor grading of clothes) will provide a barrier of protection for the athlete. Athletes, with positive nasal colonization and who suffer recurrent bouts of MRSA or MSSA skin infections, should use twice daily mupirocin for 7–10 days [1].

6.3.1.2 Pitted Keratolysis

Corynebacteria or *Micrococcus* causes pitted keratolysis, another bacterial skin infection. This cutaneous disorder occurs on the soles and mimics the clinical findings of tinea pedis (athlete's foot). The characteristic pits on the soles, especially the weight-bearing portion, distinguish it from tinea pedis (Fig. 6.8) [25].

Wood's lamp examination of the infected area fluoresces coral red. Topical clindamycin or benzoyl peroxide clears the infection. To prevent pitted keratolysis, extreme athletes should wear moisture-wicking, synthetic socks [21].

6.3.2 Viruses

In addition to bacterial infections, extreme athletes endure multiple attacks on their skin by various viruses.

6.3.2.1 Herpes Simplex Virus Infection

Extreme athletes develop herpes simplex virus infections (most commonly HSV-1) either from close skin contact with another infected athlete or from reactivation of a previously acquired herpes simplex infection. Exposure to ultraviolet radiation predictably causes this reactivation [26]. Extreme athletes whose activities involve snow and mountain are especially at risk. At high altitudes, the atmosphere filters little ultraviolet radiation so that the athlete's skin endures intense exposure. Furthermore snow can reflect as much as 100 % of the ultraviolet radiation so the athlete experiences a double dose of ultraviolet radiation.

Infected athletes will first experience a burning or tingling without any obvious skin changes. The lesions related to reactivation frequently occur on the lips, while the lesions acquired from skin-to-skin contact occur most commonly on the neck, face, and arms. Nonspecific erythema subsequently develops in the area, and a fully mature lesion demonstrates grouped vesicles on an erythematous base (Fig. 6.9) [27].

Until these characteristic findings develop, herpes simplex virus infections may mimic impetigo, tinea corporis, acne, and dermatitis. Culture or immunofluorescence confirms the diagnosis.

Two grams of valacyclovir taken twice in 1 day makes the lesion noninfectious after 5 days. Extreme athletes should only use their own equipment; they should also carefully apply sunscreen to their lips before sports participation to prevent

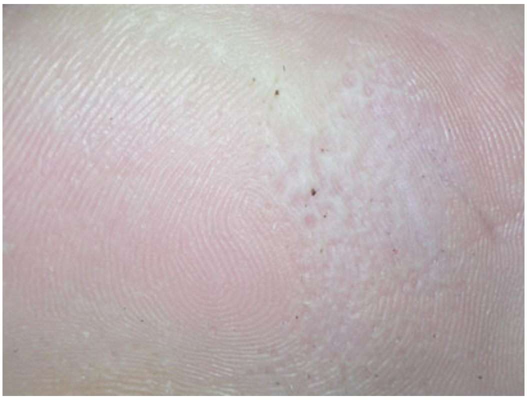

Fig. 6.8 Unlike tinea pedis, pitted keratolysis possesses craterlike pits on the sole

Fig. 6.9 Grouped vesicles on an erythematous base characterize herpes simplex virus infection of the skin

reactivation of herpes simplex virus infection [28]. Taking prophylactic oral valacyclovir (one gram daily) successfully decreases the incidence of herpes simplex virus infection [29].

6.3.2.2 Verruca (Warts)

Extreme athletes often acquire callosities. While these calluses often confer a protective quality for the extreme athlete, such thickened areas of the skin may harbor human papillomavirus (the cause of verruca). If an athlete develops pain in a callus, one should consider the possibility of a concomitant verruca. Classically, verruca demonstrates a well-defined, verrucous papule with black dots (Fig. 6.10).

With a sharp instrument, the clinician can pare the area to determine the etiology of the thickened area. A callus will maintain the presence of the skin markings, whereas a wart will lose the skin ridges and instead have black dots that represent capillary hemorrhages; a corn possesses a white central core [1, 21].

Destructive methods (most frequently involving liquid nitrogen) remain the mainstay of wart therapy; however, this approach results in pain and may thwart an extreme athlete's ability to continue the sport for several days. As such, more conservative measures suit athletes better. A slow approach to the treatment of warts includes soaking the wart for 10 min, scrubbing the area with a pumice stone, applying salicylic acid (16 %), and covering with duct tape. This procedure repeats nightly until the wart resolves [1]. Recalcitrant warts may necessitate using topical prescriptions (for instance, 5-fluorouracil or imiquimod) to replace the over-the-counter salicylic acid. Athletes must wear shoewear while walking along pool decks and in locker rooms and showers. When using weight-lifting equipment, extreme athletes should wear gloves that only they use; sharing this type of equipment facilitates the spread of warts [1].

6.3.3 Fungi

Fungal cutaneous infections also commonly occur in athletes and can affect their skin and nails.

6.3.3.1 Tinea Versicolor

Extreme athletes who compete in warm and humid condition often develop tinea versicolor. This skin ailment, caused by Pityrosporum, affects the upper layers of the epidermis and can cause dyspigmentation of the skin. The hypopigmented variety of tinea versicolor may resemble vitiligo, pityriasis alba (an eczema-like condition), hypopigmented seborrheic dermatitis, or progressive macular hypomelanosis. The hyperpigmented variety can confuse the clinician for acanthosis nigricans and confluent and reticulated papillomatosis of Gougerot and Carteaud (Fig. 6.11) [21].

Fig. 6.10 Paring this verruca would reveal the characteristic black dots of the pericapillary hemorrhages

Fig. 6.11 The scale of tinea versicolor may not be readily apparent until it is scraped with a glass slide

To confirm the diagnosis, the clinician can scrape the area with the edge of a glass slide to get sufficient scale on a separate glass slide. Addition of potassium hydroxide and examination under the microscope reveal multiple small round spores and short admixed hyphae. The combination of these two features is the so-called "spaghetti and meatballs" characteristic of tinea versicolor (Fig. 6.12) [1].

Both topical and oral therapies clear tinea versicolor. Affected athletes should apply selenium sulfide 2.5 % lotion or shampoo to the eruption and wash it off 10–15 min later. They should repeat this application daily for 1 week; to keep the eruption in remission, athletes can reapply the lotion or shampoo once weekly. Oral therapies with fluconazole can also clear the eruption and avoid potentially messy topical applications. These oral medications may cause significant side effects in athletes with preexisting liver problems or who take other medications that affect their liver [1].

6.3.3.2 Tinea Pedis

Extreme athletes who, to perform their sport, need to wear occlusive footwear risk developing tinea pedis. Epidemics have occurred in many athletes [30–33]. Tinea pedis, more commonly known as athlete's foot, can appear in three different morphologic manners. *Trichophyton rubrum* causes both interdigital and moccasin-like tinea pedis, while *Trichophyton mentagrophytes* causes the vesicular variety of athlete's foot. The former variants infrequently present with any symptoms, but the latter inflammatory infections frequently result in pruritus and irritation that prompts the infected to seek medical attention [1, 21].

Extreme athletes often believe that the relatively asymptomatic eruptions of interdigital or moccasin tinea pedis reflect, simply, dry skin. This disregard of their foot skin health can result in superinfection with bacteria. The inflammatory tinea pedis (vesicular type) causes redness, tiny blisters, and pruritus most frequently on the instep of the sole (Fig. 6.13).

Athletes and clinicians very often mistake this infection for an allergy to dyes in their socks or athletic footwear. Scraping the scale onto a glass slide to do a potassium hydroxide examination reveals long branching hyphae that typifies tinea pedis. Infected athletes need to apply topical fungicidal agents such as ciclopirox twice daily. Most clinicians prematurely discontinue this topical therapy; 8–12 weeks is often necessary for complete clearance. Occasionally, the athlete will have concomitant hyperkeratosis (very thick scaling skin) on the soles. In these cases, topical application will not sufficiently penetrate the thickened area. To facilitate the absorption of the medication, the athlete can first soak the affected area in lukewarm water for 5–10 min. Severe

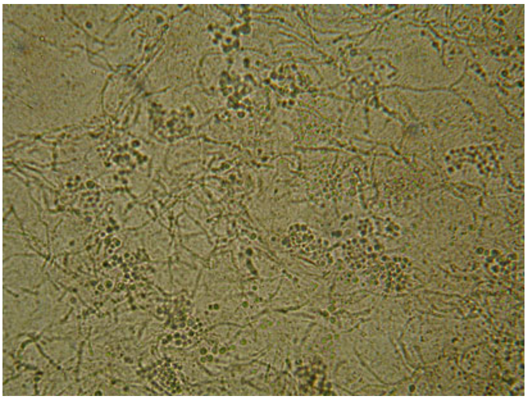

Fig. 6.12 The scale of tinea versicolor, once scraped and placed under the microscope, demonstrates short hyphae and groups of small round spores

Fig. 6.13 Extreme athletes with inflammatory (vesicular) tinea pedis often complain of pruritus

cases of tinea pedis may require oral antifungal agents daily for 4–6 weeks.

Recurrence is common, and as such athletes need to focus on prevention. During their pursuits, extreme athletes need to wear synthetic moisture-wicking socks that keep their feet relatively cool and dry. Novel new products such as cocona made, in part, from coconut shells represent a major advance in moisture-wicking technology. Additionally at-risk athletes should apply once weekly topical antifungal agents to their feet to help prevent infection. Lastly, no athlete should go barefoot on communal surfaces, such as shower floors, locker room floors, or pool decks [1].

6.3.3.3 Onychomycosis

The same fungal organisms that create athlete's foot can also infect the toenails. The hallmarks of onychomycosis include thickened, yet brittle, yellow nails with subungual debris (Fig. 6.14).

Similar findings occur in athletes' toenail but rather reflect a noninfectious entity caused by constant or abrupt trauma to the toenails. To complicate the accurate diagnosis even further, dystrophic nails of athlete's toenail more easily acquire secondary infection with dermatophyte [21]. To confirm the diagnosis of onychomycosis, clinicians should send the subungual debris to the laboratory for PAS examination [1]. Unfortunately, current oral therapies for onychomycosis fail to eradicate the organism in about half of the patients; furthermore, reinfection is very common. Infected athletes should not use the same nail clippers for affected and unaffected nails. Such indiscriminant use potentiates the spread from affected to unaffected nails.

Fig. 6.14 This athlete has developed fingernail onychomycosis as a result of their tinea manuum

Conclusion

Extreme athletes endure severe environments and their skin bears the brunt of this intensity. Infections, trauma, and allergies plague the athlete at every turn. Attention to preventative techniques helps assuage the damage to the athlete's cutaneous barrier. Rapid identification and treatment of these dermatologic problems allows the extreme athlete to continue to pursue their sport with the least disruption to their routine.

References

1. Adams BB. Sports dermatology. New York: Springer Science and Business Media LLC; 2006.
2. Cortese TA, Fukuyama K, Epstein W, et al. Treatment of friction blisters. Arch Dermatol. 1968;97:717–21.
3. Adams BB. Jogger's toenail. J Am Acad Dermatol. 2003;48:58–9.
4. Mailler EA, Adams BB. Skin manifestations of running. J Am Acad Dermatol. 2006;55:290–301.
5. Wilkinson DS. Black heel a minor hazard of sport. Cutis. 1977;20:393–6.
6. Doukas DJ, Holmes J, Leonard JA. A nonsurgical approach to painful piezogenic pedal papules. Cutis. 2004;73:339–40.
7. Boni R, Dummer R. Compression therapy in painful piezogenic pedal papules. Arch Dermatol. 1996;132:127–8.
8. Woodrow SL, Brereton-Smith G, Handifiedl S. Painful piezogenic pedal papules: response to local electro-acupuncture. Br J Dermatol. 1997;136:628–30.
9. Cohen PR, Eliezri YD, Silvers DN. Athlete's nodules. Cutis. 1992;50:131–5.
10. Adams BB. Sports dermatology. Adolesc Med. 2001;12:305–22.
11. Moehrle M, Koehle W, Dietz K, Lischka G. Reduction of minimal Erythema dose by sweating. Photodermatol Photoimmunol Photomed. 2000;16:260–2.
12. Rigel DS, Rigel EG, Rigel AC. Effects of altitude and latitude on ambient UVB radiation. J Am Acad Dermatol. 1999;40:114–6.
13. Englund EL, Adams BB. Winter sports dermatology: a review. Cutis. 2009;83(1):42–8.
14. Kockentiet B, Adams BB. J Am Acad Dermatol. 2007;56:1048–55.

15. Adams BB. Exercise-induced anaphylaxis in a marathon runner. Int J Dermatol. 2002;41:394–6.
16. Shadick NA, Liang MH, Partridge AJ, et al. The natural history of exercise induced anaphylaxis: survey results from a 10-year follow-up study. J Allergy Clin Immunol. 1999;104:123–7.
17. Kirkland EB, Adams BB. Methicillin-resistant *Staphylococcus* aureus and athletes. J Am Acad Dermatol. 2008;47:630–2.
18. Begier EM, Frenette K, Barrett NL, et al. A high-morbidity outbreak of methicillin-resistant *Staphylococcus* aureus among players on a college football team, facilitated by cosmetic body shaving and turf burns. Clin Infect Dis. 2004;39:1446–53.
19. Kazakova SV, Hageman JC, Matava M, et al. A close of methicillin-resistant *Staphylococcus* aureus among professional football players. N Engl J Med. 2005;352:468–75.
20. Romano R, Lu D, Holtom P. Outbreak of community-acquired methicillin-resistant *Staphylococcus* aureus skin infections among a collegiate football team. J Athl Train. 2006;41:141–5.
21. Adams BB. Skin infections in athletes. Expert Rev Dermatol. 2010;5:567–77.
22. Montgomery K, Ryan TJ, Krause A, Starkey C. Assessment of athletic health care facility surfaces for MRSA in the secondary school setting. J Environ Health. 2010;72:8–11.
23. Creech CB, Saye E, Mckenna BD, et al. One-year surveillance of methicillin-resistant *Staphylococcus* aureus nasal colonization and skin and soft tissue infections in collegiate athletes. Arch Pediatr Adolesc Med. 2010;164:615–20.
24. Rihn JA, Posfay-Barbe K, Harner CD, et al. Community-acquired methicillin-resistant *Staphylococcus* aureus outbreak in a local high school football team unsuccessful interventions. Pediatr Infect Dis J. 2005;24:841–3.
25. Wohlrab JR, Marsch WC. Keratolysis sulcata (pitted keratolysis): clinical symptoms with different histological correlates. Br J Dermatol. 2000;143:1348–9.
26. Mills J, Hauer L, Gottlieb A, et al. Recurrent herpes labialis in skiers. Am J Sports Med. 1987;15:76–8.
27. Adams BB. Skin infections in athletes. Dermatol Nursing. 2008;20:39–44.
28. Rooney JF, Bryson Y, Mannix ML, et al. Prevention of ultraviolet-light-induced herpes labialis by sunscreen. Lancet. 1991;338:1419–22.
29. Spruance SL, Hamill ML, Hoge WS, et al. Acyclovir prevents reactivation of herpes simplex labialis in skier. JAMA. 1988;260:1597–9.
30. Attye A, Auger P, Joly J. Incidence of occult athlete's foot in swimmers. Eur J Epidemiol. 1990;6:244–7.
31. Caputo R, De Boulle K, Del Rosso J, Nowicki R. Prevalence of superficial fungal infections among sports-active individuals: results from the Achilles survey, a review of the literature. J Eur Acad Dermatol Venereol. 2001;15:312–6.
32. Kamihama T, Kimura T, Hosokawa JI, Ueji M, Takase T, Tagami K. Tinea pedis outbreak in swimming pools in Japan. Public Health. 1997;111:249–53.
33. Pickup TL, Adams BB. Prevalence of tinea pedis in professional and college soccer players versus non-athletes. Clin J Sport Med. 2007;17:52–4.

7 Medical Support for Expedition-Length Adventure Races

Ryan Ernst and David Townes

7.1 Introduction

Expedition-length adventure races have grown in popularity since the first well-organized events were held in the early 1980s. Some of the early major events include New Zealand's Coast-to-Coast and Alaska's Wilderness Classic. Other well-known events followed including New Zealand's Raid Gauloises and the Southern Traverse and the United States' Eco-Challenge and Primal Quest. The growth and development of the sport have continued with the Adventure Race National Championships held under the direction of the United States Adventure Racing Association (USARA) and the Adventure Race World Series culminating in the Adventure Race World Championship [1]. In addition to these expedition-length races, there are numerous shorter races held throughout the world.

Expedition-length adventure races are most often competitive team events that require teams to perform multiple disciplines including, but not limited to, trekking, mountain biking, flat and white-water rafting/kayaking, ropes work, and navigation over a course that may cover hundreds of miles and take up to 10 days or more to complete. Most races require teams to have four or five members, with at least one member from each gender, racing together, with each team member completing each discipline along the course.

Unique to many of these events, there is no set course. Rather, teams must pass through a set of checkpoint and transition areas (TA), where teams change disciplines, from mountain biking to trekking, for example. Teams are provided maps and the Universal Transverse Mercator (UTM) coordinates for each of the checkpoints and transition areas through which they must pass. Between checkpoints and/or TAs, teams decide the best route for their team depending on conditions and the strengths and weakness of the team. A team with strong white-water skills may opt to take on a rapid while another team may choose to portage around it. Similarly, a team with strong trekkers may go over a ridge while other teams may opt to go around it. Also unique to these events is the absence of built-in rest periods as these are not staged events. Once the race begins, teams are permitted to race around the clock and thus must strategize if and when to rest. The winning team is the one to complete the course with the fastest overall time after any penalties have been allocated. In many of the major events, prize money is awarded and several of the top teams race professionally.

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During expedition-length adventure races, teams are governed by the “rules of travel.” This set of rules or instructions dictates when and how teams may progress on the course. Examples include specifying if and when a team may utilize a paved road or restricting teams from being on white water at night in the interest of safety. The rules of travel also dictate what safety and communication equipment is required. Examples include mandatory use of appropriate helmets while riding bicycles or climbing and personal flotation devices (PFD) while on the water.

Penalties are issued to teams for infractions in the rules of travel. For example, minor breaches such as travel on an unapproved section of paved road might result in an additional hours being added to the team’s total time at the end of the race while a major infraction, often related to safety, such as not wearing a helmet during a mountain bike section, may result in disqualification of that team.

The rules of travel also specify which medications, including potential performance-enhancing medications, interventions, and treatments, are permitted and prohibited. They also include parameters for the provision of medical care during the event including implications for receiving medical assistance during the event from the event medical staff. This ranges from additional hours being added to the team’s total time at the end of the race to medical withdrawal of the team from the event.

Expedition length adventure races are unique among wilderness and endurance events in that they require performance of multiple disciplines, have no set course, are not staged, and have no built-in breaks or rest periods and occur over long distances and many days in remote and austere environments.

For the purpose of provision of medical support, events have been divided into four categories. In category I events, spectators are in one location during the course of the event. Examples include concerts and stadium sporting events. In category II events, spectators change location during the event such as during golf tournaments and may participate in the event such as Mardi Gras celebrations. Category III events occur over large geographic areas with participants often outnumbering spectators such as ultramarathons or long-distance bicycle rides. Category IV events occur in rough terrain often in remote locations where participant location and communication are uncertain, necessitating SAR and prolonged transport time to definitive care. Expedition-length adventure races are category IV events [2]. The complexity of the required medical support plan increases with each category of event. Expedition-length adventure races present significant challenges for those charged with provision of medical support for these events and require a comprehensive *medical support plan* unlike that for any other category of event.

7.2 Medical Support Plan

During expedition-length adventure races, medical care is commonly delivered at medical stations positioned at every TA as well as at key checkpoints along the course (Figs. 7.1 and 7.2).

Many of the critical details about the provision of medical care for these events are outlined in the medical support plan.

Development of the medical support plan must take into consideration many factors including the number of participants, the disciplines required, the location and time of year of the event, potential endemic disease, availability of local search and rescue (SAR), emergency medical services (EMS) and other prehospital capabilities, quality and level of local “definitive” medical care, limitations of communication, and the broad range of potential injury and illness encountered during these events.

The medical support plan should be comprehensive based on all of these factors and include contingency planning when appropriate. This should all be based on anticipation of need in both worst- and best-case scenarios. At a minimum, the basic objective of the medical support plan should include timely access and triage of patients, on-site care for minor injuries and illnesses, and stabilization and facilitation of transport of more seriously ill or injured patients to a higher level of care.

Fig. 7.1 “Self-foot care station” in an expedition-length adventure race

Some of the key components of the medical support plan include *personnel, equipment and supplies, communication and participant tracking, logistics and transportation, scope of practice, and medical assistance penalties and disqualification*.

The components of the medical support plan are shown in Table 7.1.

7.2.1 Personnel

Appropriate staffing of the on-site medical team is essential for the provision of optimal medical support for expedition-length adventure races. In the majority of events, there is a medical director and medical team members all of whom may be volunteers. Team members should have a collective balance of experience in event medicine, wilderness medicine, emergency medicine, and prehospital care including SAR. Those with experience in previous expedition-length adventure races may be particularly valuable members of the team. Staffing of each medical station should include individuals with appropriate training, experience, and skills in three general areas of expertise: (1) patient assessment, (2) IV placement and fluid and medication administration, and (3) patient packaging for evacuation. These skills may be represented by one individual but more likely multiple individuals will be necessary to include the appropriate scope of skills.

In addition to these three main areas of expertise, additional personnel may be invaluable in particular settings. For instance, foot care including treatment of blisters is a very common chief complaint during expedition-length adventure races especially after long sections requiring foot travel. It is beneficial to have personnel with expertise in foot care stationed at the TA after these sections as there will likely be a large number of participants requiring treatment of foot-related problems [2–4]. This is less likely to be the case after mountain biking or boating sections of the course.

Fig. 7.2 The author examines a participant during the Primal Quest Expedition Length Adventure Race

Table 7.1 Components of the medical support plan

Personnel: Listing of the type and number of personnel required
Equipment and supplies: Listing of the type and number of equipment and supplies required
Communication and participant tracking: Outlining communication and participant tracking guidelines for use in emergency medical situations
Logistics and transportation: Outlining the location and transportation of personnel, equipment, and supplies during the event. This is especially important for critical personnel and limited resources such as portable altitude chambers and ambulances
Scope of practice: Including guidelines for on-site treatment and evacuation of common injuries and illness. This should include the contact information and capability of the local SAR, EMS, and hospitals for each point along the course
Medical assistance penalties and disqualification: Outlining the penalties for acceptance of medical care during the event and criteria for medical disqualification including significant illness or injury as well as banned substance use

The ideal staffing for a medical station is a medical team with a diverse and complimentary skill set, a team attitude, and an ability to work together in a nontraditional and often demanding context.

7.2.2 Equipment and Supplies

One of the biggest challenges in provision of medical support for expedition-length adventure races is predicting both the type and amount of medical equipment and supplies that will be necessary. Each medical station should be supplied with adequate equipment and supplies for the duration of the event. This should be based on anticipation of need in both the best- and worst-case scenarios.

A careful review of the course may help in predicting anticipated need. It is also useful to review previous events. Even with the careful review and knowledge of previous events, anticipation of need may be very challenging as each expedition-length adventure race is different. A previously cited example is the 2002 Primal Quest held in Telluride, Colorado. In pre-race screening, few athletes reported asthma including exercise-induced asthma; however, during the event, there were a large number of participants who requiring beta-agonist inhalers for wheezing, thought to be secondary to a combination of poor air quality from forest fires in the area as well as a viral respiratory illness that spread among the participants [4]. During the same event held a year later in South Lake Tahoe, California, almost no beta-agonist inhalers were administered; however prednisone was in short supply due to many of the participants contacting poison ivy along the course.

A comprehensive list of all the equipment, supplies, and medications should be included in the medical support plan and a copy available at each medical station. In general, all medical stations should be stocked with the same supplies. The amount of supplies may vary from one medical station to the next depending on anticipated need; however the basic supplies should be the same. This standardization of equipment is helpful as medical staff can be informed of what is available and will not look for items that are not stocked. In addition creation of standard kits or carts should allow for familiarity, increased efficiency, and reduced errors. The amount of each supply may vary depending on anticipated need. For example, the stock of foot care supplies should be in greater amounts at the TA after a long section of the course requiring foot travel compared with the TA after a boating section of the course. In addition there may be specialized pieces of equipment where placement is critical. For example, a portable altitude chamber should be placed on the course where it is anticipated that high-altitude illness will occur and descent may not always be possible.

Equipment and supplies should be stored in durable, portable containers. Items should be in the original packaging, placed in clear plastic bags or storage containers labeled with the contents in the appropriate relevant languages.

7.2.3 Communication and Participant Tracking

Expedition-length adventure races utilize different methods of communicating between race staff including medical staff and race participants. Ideally, a primary and secondary system should be utilized, as no communication system is consistently reliable in these environments. Mobile or cellular telephones offer private, relatively low-cost communication but require a network that may not be available in the environments in which these events take place. Satellite phones also offer private communication and over a worldwide network however at significant cost. Radios have the advantages of reliable communication in a wide variety of terrain; however they may require setting up repeaters that require power and do not offer private communication which is a disadvantage for medical communications. It is strongly recommended that two communication systems be utilized such as radios as a primary system and satellite phones as a secondary system.

Given the limitations in communications including inherent unreliability, it is important to utilize a standard system for teams to quickly and accurately relate important information about the situation to the medical and event staff. One system that has been used is a three-tier classification of medical emergencies. Class 1 emergencies are minor, requiring no evacuation, and the participant will proceed with their team and receive evaluation and treatment at the nearest medical station. Examples include a sprained wrist or sunburn. Class 2 emergencies are not life threatening but require evacuation. An example is a tibia-fibula fracture. Class 3 emergencies are potentially life threatening, requiring immediate evacuation. Examples include a head injury or respiratory distress. Utilizing this system, a team can quickly relate the urgency of the situation in the event communication is not consistent.

When an injury or illness occurs along the course that requires evacuation, it is critical to be able to quickly and accurately locate the ill or injured participant. As previously discussed, communication can be unreliable, and even when communication is available, participants may not be able to accurately relate their position.

Global Positioning Systems (GPS) technology has become the standard for tracking participants in large expedition-length adventure races. Compared with alternatives, it provides increased accuracy and capability for locating and tracking participants and greatly enhances the ability of event staff including medical staff to coordinate and execute a rescue and medical response when necessary.

During some expedition-length adventure races, teams may carry a small case containing a GPS tracking unit and a radio or satellite phone. These devices send a signal every hour giving the location of the team to event staff. The device has no display so the team cannot use it to determine their location. In the event of an emergency, the team flips a switch on the device that changes the signal received by event staff to a distress signal, indicating there is a problem. The team then relates the nature of the emergency to race staff utilizing the radio or satellite phone contained in the device. Utilizing this system, race staff quickly learns the nature of the emergency and the exact location of the team.

If such a system is utilized, a secondary system should also be in place, as GPS and communication devices such as radios and satellite phones may not work in these remote and rugged environments. The ideal overall tracking system will require a combination of the multiple modalities. What works best will depend on the location, course, terrain, existing infrastructure, weather, and budget of the particular event.

7.2.4 Logistics and Transportation

Appropriate location of medical stations along the course and placement of personnel, supplies, and equipment is essential to ensure effective medical support for the event. In the majority of expedition-length adventure races, the main medical stations are located at TA. There may be great distance between TA, often 25 miles or more, which is significantly longer than in marathons or ultramarathons, that may have spacing of medical stations every 1 mile or 5 miles, respectively. Due to the long distance between TA, medical stations are also placed at strategic locations throughout the course, including certain checkpoints and utilizing mobile medical teams, taking into consideration anticipation of need. Utilizing alternative locations for medical stations such as checkpoints and mobile teams may be very useful to provide adequate coverage for expedition-length adventure races that may have a 400-mile or longer course.

Each medical station should have a binder with critical information specific to that station from the medical support plan. For instance, for each main medical station along the course, most of which will be located at TA, it is important to list all access points in the binder. This should include maps of road access for emergency vehicles coming to the medical station to pick up a patient and transport them to the appropriate facility. In addition, this should include the location of the closest landing zone (LZ) for a helicopter if evacuation by air becomes necessary. In addition, the binder should contain the location of the medical station in language that the local EMS or SAR personnel can understand. This may include a description of the location in the local language and using local terms. For example, instead of identifying a medical station as “Medical Tent #4,” it should also be identified with local landmarks, such as “Ocean Beach Trailhead off County Road 33.”

Each medical station should be stocked with adequate supplies. Certain large or expensive pieces of equipment, such as portable hyperbaric chambers, may need to be moved from one medical station to another during the event. They may need to be leapfrogged from one medical station to another as the race progresses. The movement of critical supplies and equipment should be planned out ahead of the race. Flexibility should be built in, as timing of the event and use of the equipment and supplies may be impossible to accurately predict.

Transportation for both medical teams and evacuation of patients is an important consideration, given both the large geographic area typically covered by an expedition-length adventure race and the rugged variety of terrain. The medical support plan should include the specific plan for evacuation for every portion of the course.

This includes listing local SAR and EMS if available as well as the location of the closest facility and comprehensive facility along with their capacities and capabilities. For each point along the course including the medical stations, will local SAR and EMS respond or will the event be responsible for locating and transporting ill or injured participants to a location where care can be transferred to the local medical system? Some parts of the course may be accessible by ALS ambulance; however large sections of the course may be accessible only by 4-wheel-drive vehicle, watercraft, and helicopter. It is preferred to utilize local SAR and EMS including local air medical resources as they are familiar with the area and systems and communication standards and treatment guidelines will already be in place.

Establishing accessibility of the local emergency network such as 911 or similar, at each point along the course, should occur prior to event operations. If such a network is in place, for each position along the course, it is important to know if it can be accessed using cellular/mobile phones or if satellite phones are required. For both out-of-area cellular phones and satellite phones, access should be tested. If such as system is not in place, it is important to know how to contact local SAR and EMS. In each case, protocols for notification and activation of local SAR, EMS, and hospitals should be disseminated to medical personnel and contained in the medical support plan in a binder at all medical stations along the course.

In some events, local EMS and SAR will not have sufficient capacity or capabilities and the event will be responsible for evacuation and transport of patients to local facilities. In these situations, it may be necessary to utilize event resources, such as event vehicles or helicopters normally used for media or event staff transportation, for patient evacuation and transport. The ability to provide these additional services will be very dependent on the pilot's experience, knowledge of the area, and comfort level. The plan for this alternative use of the helicopter should be well established and agreed upon by all parties prior to the event.

If the event budget will allow, in situations where local SAR or EMS is insufficient, the event staffing should include privately hired staffed advanced life support (ALS) ambulances that are positioned strategically along the course.

7.2.5 Scope of Practice

A basic objective of the medical support plan for any expedition-length adventure race is to provide definitive care for patients with minor injury and illness and stabilize and facilitate evacuation of patients with severe injury and illness. The specifics about the types of injury and illness that may receive definitive treatment by event medical staff will depend on a number of factors including the location of the event and local access to quality definitive medical care and the qualifications, training, and experience of the medical providers on the event medical staff. This "scope of practice" should be outlined in the medical support plan.

7.2.6 Injury

The medical support plan must take into account the anticipated scope of injury and illness for the participants and potentially spectators and staff. Injuries are common during expedition-length adventure races, although the majority relatively minor, and few require evacuation or withdrawal from the event. At the 2005 World Adventure Racing Championships, 2.5 injuries per 1000 race hours were reported. During the event, 28 of 42 injuries were lower-extremity soft tissue injuries. These were the most common injury to require medical care. There was no significant association of injury during competition with age, gender, pre-race injury, pre-race illness, days off, or training hours [5].

Similarly, findings from the 2002 and 2003 Primal Quest in Colorado and Lake Tahoe, respectively, also revealed the most common injury to be soft tissue (70 % and 48 %). Orthopedic injuries were the second most common type of injury. During both of these events, blisters were the most common injury requiring medical care [3].

These results were also consistent with a study at the Caloi Adventure Camp Race in Brazil,

Table 7.2 Distribution of injury and illness (by type, number and fequency) during the 2002 Primal Quest Expedition Length Adventure Race in Telluride, Colorado ($n = 302$)

Type of injury/illness	No. of cases ($n = 302$)	% of cases
Skin/soft tissue	145	48.0
Blister	99	32.8
Abrasion/contusion	21	7.0
Laceration	18	6.0
Rash	4	1.3
Cellulitis	3	1.0
Respiratory	55	18.2
URI/bronchitis	36	12.0
RAD/asthma	19	6.3
Altitude	36	11.9
AMS[a]	34	11.3
HAPE[b]	2	<1
Orthopedic	29	9.6
Lower extremity	25	8.3
Knee	12	4.0
Ankle	11	3.6
Foot	1	<1
Lower leg	1	<1
Upper extremity	2	<1
Wrist	2	<1
Thorax/back	2	<1
Dehydration	21	7.0
Gastrointestinal	6	2.0
HEENT[c]	5	1.7
Eye	3	1.0
Ear	1	<1
Nose	1	<1
Genitourinary	3	1.0
Other	2	<1

Table was reprinted with permission from Townes et al. [4]

[a] Acute mountain sickness

[b] High-altitude pulmonary edema

[c] Head, eye, ear, nose, and throat

Table 7.3 Distribution of injury and illness (by type, number and frequency) during the 2003 Primal Quest Expedition Length Adventure Race in Lake Tahoe, California ($n = 406$)

Type of injury or illness	No.	%
Skin and soft tissue	286	70.4[a]
Blister	185	45.6
Abrasion/contusion	43	10.6
Rash	32	7.9
Nail injury	9	2.2
Avulsion/laceration	9	2.2
Burn	4	1.0
Abscess/cellulitis	4	1.0
Orthopedic	60	14.8
Upper-extremity sprain/tendonitis	30	7.4
Lower-extremity sprain/tendonitis	24	5.9
Other	6	1.5
Respiratory	15	3.7
Upper respiratory tract infection/ bronchitis/pneumonia	10	2.5
Reactive airway disease/asthma	5	1.2
Dehydration/heat illness	15	3.7
Head/eyes/ears/nose/throat	13	3.2
Bee/sting/envenomation	4	1.0
Bee sting	3	<1.0
Snake bite	1	<1.0
Gastrointestinal/genitourinary	3	<1.0
Neurological	3	<1.0
Hypothermia	2	<1.0
Others	5	1.2
Total	406 ~ 100	

Table was reprinted with permission from McLaughlin et al. [3]

[a] Percentages have been rounded one decimal place.

which found abrasions and cuts were the most common injuries (37 % and 25 %, respectively), primarily of the lower limb (49 %), with sprains and fractures being second most common. The same study found that the trekking portion of the race accounted for the majority of injuries [6] (Tables 7.2 and 7.3, Fig. 7.3).

In each of these investigations, soft tissue injuries of the lower extremity were among the most common reason a race participant needed on-site medical care. Taking these findings into account, the medical support plan should include supplies, equipment, and staff to treat a potentially large number of lower-extremity soft tissue injuries, blisters, sprains, and possible fractures. Given that blisters have been the most common reason for race participants to require medical care, medical staff should include personnel familiar and willing to treat large numbers of patients with blisters. It is important that they be supplied with sufficient supplies, especially at key points along the course including long trekking sections where the occurrence of blisters is

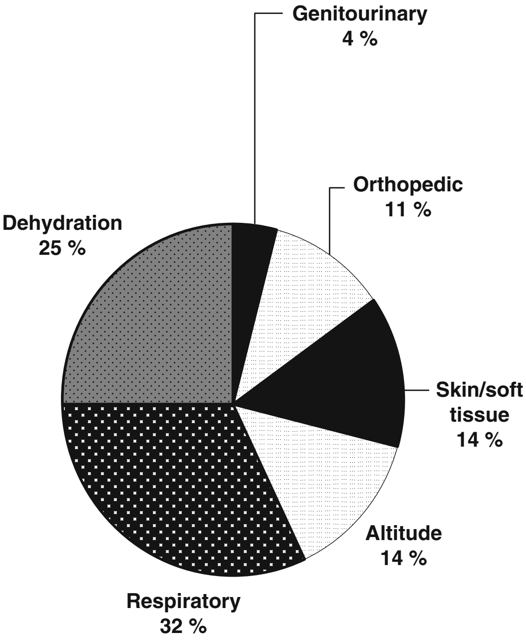

Fig. 7.3 Percentage distribution of injury and illness resulting in withdrawal from the event by type during the Primal Quest Expedition Length Adventure Race 2002 ($n=28$) (Image was reprinted with permission from Townes et al. [4])

anticipated. Being prepared to treat minor injuries such as blisters should not replace equipment, supplies, and personnel prepared to treat other injuries including trauma to the head, neck, and torso. While likely less common than more minor injuries, these potentially more serious injuries should not be overlooked. Equipment, supplies, and personnel should include capability to provide fluid resuscitation, immobilization, and packaging for transport for these potentially seriously injured patients.

While minor trauma and soft tissue injury comprise the most common reasons to require medical attention, environmental exposure also may also be a contributing factor. Depending on the temperature, humidity, and altitude experienced on the course, environmental factors may contribute to a significant number of participants requiring medical attention. This can vary widely between events and it may be challenging to predict burden on injury and illness of environmental factors.

For example, during the 2-day Winter Classic held in Victoria, Australia, 21 % of respondent competitors reported symptoms of exposure [7]. In contrast, at the 2003 Primal Quest in Lake Tahoe, California, where daily temperatures averaged 13 °C and rarely dipped below freezing, there were only two medical encounters for hypothermia [4].

During the 2002 Primal Quest, the race began at 9500 ft and peaked at 13,500 ft. The pre-race prevalence of acute mountain sickness was 4.5 % but altitude illness comprised 11.9 % of all medical encounters during the event and accounted for 14.3 % of all of the medical withdrawals from the event [8].

Past experience would suggest that temperature, humidity, and altitude should be thoroughly considered when planning and predicting injury and illness patterns. In addition, athletes and staff should be trained in recognizing heat and cold injuries and altitude illness. It is important to provide information to staff and spectators who may also be at risk for environmental illness and encourage preventative measures when extremes of temperature or elevation are expected.

7.2.7 Illness

Although generally less common than injury, illness does occur in adventure race athletes both during competition and training. One investigation found that “medical illness” occurred at a rate of 1 illness / 1000 race hours. The same study also found that 52 % of athletes reported a medical illness in the 6 months preceding the race. About one third of these illnesses were considered severe [5].

Several studies have demonstrated that the most common medical illnesses encountered during competition are respiratory, including upper respiratory infection, bronchitis, and asthma/reactive airway disease. Respiratory illness represented 3.7 % of all medical encounters at the Primal Quest in 2003 and 28.8 % of all medical encounters at the World Adventure Racing Championships in 2005 [3, 5]. During the Primal Quest 2002, respiratory illness accounted for 18

% of all medical encounters but 32 % of all medical withdrawals from the event, which was the most common reason [4].

Given the extreme endurance nature of expedition-length adventure races and the environments in which they occur, the potential for dehydration and related complications is considerable. During the 2002 Primal Quest in Colorado, average daily maximum temperatures were 26.6 °C (80 F); dehydration comprised 7 % of medical visits [4]. A year later in Lake Tahoe during the same event, where daily temperatures averaged 13 °C and dipped below freezing, only 3.7 % of medical visits were for dehydration/hyperthermia [3].

Endemic infectious diseases may also be a consideration depending on the specific event. It is important to have a good understanding of any infectious diseases endemic to the region or area where the event is being held. Members of the medical team should be familiar with the common signs and symptoms, treatment, transmission, and prevention of diseases endemic to the area. Athletes should be cautioned about the potential for acquiring such diseases including prevention strategies and signs and symptoms to watch for during the event and during the post-race period if warranted.

There have been multiple reports of outbreaks of leptospirosis during adventure races documented in the literature. At the Ecochallenge in Borneo in 2000, leptospirosis was determined to be the cause of an outbreak of febrile illness among the athletes. Investigators from the CDC contacted 189 of the 304 participants and found that 80 of these athletes met symptomatic criteria of the case definition. Twenty-nine case patients were hospitalized. There were no fatalities. Sixty-eight percent of those tested were positive for leptospiral antibodies [9]. In 2005, about a quarter of the athletes competing in an endurance-length adventure swim in Florida developed symptoms suspicious for leptospirosis infection. Ultimately, 14 athletes tested serologically positive [10].

Additional leptospirosis outbreaks include a race in Martinique, in 2009, where 20 of 148 athletes contacted met case definition. Five were hospitalized and there were no deaths. Ten out of the 11 athletes tested were positive by polymerase chain reaction (PCR) [11]. Also, in Germany in 2006, 142 of 507 triathletes were contacted and five were found to have tested positive for leptospirosis [12]. In Austria in 2010, four confirmed cases of leptospirosis occurred after a triathlon [13]. In Borneo, it was determined that risk factors include swallowing river water or submersion in river water [9]. In Germany and Austria, heavy rains prior to the race were thought to have contributed to the incidence of infection [12, 13].

In 2001, a Finnish athlete competing in Brazil suffered a laceration on his arm during competition, which was slow to heal and developed purulent drainage and increased pain over the following week. Eventually, larvae were discovered in the wound and identified as *Cochliomyia hominivorax*, or screwworm fly [14].

In South Africa in 1997 during the Raid Gauloises, of the 450 participants, an outbreak of African tick bite fever (*Rickettsia africae*) was confirmed in 13 athletes, who reported systemic symptoms such as fever, headache, lymphadenopathy, and rash. Tick bites were reported in 61 % of those confirmed cases, with onset of symptoms after bite between 4 and 10 days [15].

These findings suggest that both athletes and race organizers should be made aware of the signs and symptoms of infection and also instructed on potential preventative strategies including antibiotic prophylaxis in areas with potential for leptospirosis, tick prevention and removal techniques, and proper wound care.

7.2.8 Medical Assistance Penalties and Disqualification

The medical support plan should include penalties for accepting medical care during the event and outline parameters for medical disqualification of individual racers and conflict resolution when individual racers or teams disagree with the decision of the medical team.

A specific example from Primal Quest races regarding intravenous fluids (IVF) is shown below [4]. As with any such rule, the goal is to optimize safety while establishing penalties that are significant enough that athletes will not utilize medical care for competitive advantage, in this case asking for IVF at each medical station to maximize hydration, yet, not so harsh athletes will push themselves to the point of endangering their health to stay in the event.

Intravenous Fluid Rule Used During the Primal Quest 2002–2008 [4]:

1. Athletes who receive intravenous fluid (IVF) are automatically penalized 4 h. The penalty period begins with the completion of the last liter of fluid.
2. Athletes requiring more than 2 L of IVF at one time (one medical station) or any amount of IVF at more than one time (multiple medical stations) will be automatically disqualified from the event
3. All athletes who require IVF must be evaluated and medically cleared by the race medical director or his or her designee before returning to the race. Return to the race will occur only after the 4-h penalty has been served.

When an athlete requires more extensive medical care or is deemed to be unsafe for continued participation, the athlete should be disqualified. The parameters regarding cause for disqualification should also be well established and communicated clearly, as this is a potential area of controversy. An athlete may not agree with the decision of the medical team; however, it should be well communicated that the medical director makes the final determination regarding medical disqualification. It can be helpful for the medical director to explain the situation to the other members of the disqualified athlete team or support crew in order to utilize their influence to help convince the athlete that their health and safety require medical disqualification.

Since expedition-length adventure races are competitive events with some rewarding prize money to winning teams, there is the potential for the use of performance-enhancing substances. Many events have a list of banned substances. This may be the list utilized by the International Olympic Committee.

7.3 Special Considerations About Nutrition

Due to the extreme nature, there are some special considerations in provision of medical support for expedition-length adventure races.

Use of caffeine and nutritional supplements is common among adventure race athletes. Due to the nature of these events, adventure race athletes have very high nutritional requirements and simply transporting adequate nutrition can be a challenge. The decreased appetite that many endurance athletes experience during competition may further complicate this. In an experiment designed to simulate the 2003 Eco-Motion Pro, participants simulated trekking, running, biking, and canoeing over 67 h. The athletes were found to only intake in 60 % of their energy expenditure. Of note, the vast majority of the caloric intake was in the form of food, not supplements [16]. Another study of a 24-h simulated running endurance race found that athletes took in less than 50 % of their energy expenditure [17]. Similar results were found in cyclists during the 6.5-day 2008 Race Across America. In that study, participants consumed only 67 % of their energy expenditures during the competition [18].

In another study investigating the components of adventure racers' nutritional status, both men and women were found to have inadequate vitamin and mineral intake, although overall their caloric intake was adequate for men and in excess in women [19].

Due to the continuous nature of many expedition-length adventure races, caffeine is a commonly used substance among participants. A systematic review in 2009 analyzed 21 studies investigating caffeine use and endurance performance and found variable results but overall showed a mild improvement in performance when taking moderate amounts of caffeine (3–6 mg/kg) taken generally 1 h prior to performance. Interestingly, the improvement in performance was maximized when athletes abstained from caffeine for 1 week prior to performance [20].

Conclusion

Provision of medical support for expedition-length adventure races requires development of a medical support plan based on thorough planning and anticipation of need in both the best- and worst-case scenarios. Providers should be prepared to treat a wide variety of injury including minor and major trauma and illness including infectious and endemic diseases and environmental illness.

References

1. United States Adventure Racing Association: http://www.usara.com/. Accessed on 15 July 2014.
2. Townes DA. Wilderness medicine: strategies for provision of medical support for adventure racing. Sports Med. 2005;35(7):557–64.
3. McLaughlin KA, Townes DA, Wedmore IS, Billingsley RT, Listrom CD, Iverson LD. Patten of injury and illness during expedition-length adventure races. Wilderness Environ Med. 2006;17(3):158–61.
4. Townes DA, Talbot TS, Wedmore IS, Billingsly R. Event medicine: injury and illness during an expedition-length adventure race. J Emerg Med. 2004;27(2):161–5.
5. Newsham-West RJ, Marley J, Schneiders AG, Gray A. Pre-race health status and medical events during the 2005 World Adventure Racing Championships. J Sci Med Sport. 2010;13(1):27–31.
6. Dos Santos G, Marcelo Pastre C, Lia do Amaral S, Luiz Monteiro H. Nature des lésions chez des athlètes pratiquant des sports d'aventure. Sci Sport. 2009;24:15–20.
7. Borland ML, Rogers IR. Injury and illness in a wilderness multisport endurance event. Wilderness Environ Med. 1997;8(2):82–8.
8. Talbot TS, Townes DA, Wedmore IS. To air is human: altitude illness during an expedition-length adventure race. Wilderness Environ Med. 2004;15(2):90–4.
9. Centers for Disease Control and Prevention (CDC). Update: outbreak of acute febrile illness among athletes participating in Eco-Challenge Sabah 2000-Borneo, Malaysia, 2000. MMWR. 2001;50(2):21–4.
10. Stern EJ, Galloway R, Shadomy SV, Wannemuehler K, Atrubin D, Blackmore C, Wofford T, Wilkins PP, Ari MD, Harris L, Clark TA. Outbreak of leptospirosis among adventure race participants in Florida, 2005. Clin Infect Dis. 2010;50(6):843–9.
11. Hochedez P, Rosine J, Theodose R, Abel S, Bourhy P, Picardeau M, Quenel P, Cabie A. Outbreak of leptospirosis after a race in the topical forest of Martinique. Am J Trop Med Hyg. 2011;84(4):621–6.
12. Brockmann S, Piechotowski I, Bock-Hensley O, Winter C, Oehme R, Zimmermann S, Hartelt K, Luge E, Nöckler K, Schneider T, Stark K, Jansen A. Outbreak of leptospirosis among triathlon participants in Germany. 2006. BMC Infect Dis. 2010;10:91. doi:10.1186/1471-2334-10-91.
13. Radl C, Muller M, Revilla-Fernandez S, Karner-Zuser S, de Martin A, Schauer U, Karner F, Stanek G, Balcke P, Hallas A, Frank H, Furnschlief A, Erhart F, Allerberger F. Outbreak of leptospirosis among triathlon participants in Langau, Australia, 2010. Wien Klin Wochenschr. 2011;123(23–24):751–5.
14. Seppanen M, Virolainen-Julkunen A, Kakko I, Vilkamaa P, Meri S. Myiasis during adventure sports race. Emerg Infect Dis. 2004;10(1):137–9.
15. Fournier PE, Roux V, Caumes E, Donzel M, Raoult D. Outbreak of Rickettsia africae infections in participants of an adventure race in South Africa. Clin Infect Dis. 1998;27(2):316–23.
16. Zimberg IZ, Crispim CA, Juzwiak CR, Antunes HK, Edwards B, Waterhouse J, Tufik S, de Mello MT. Nutritional intake during a simulated adventure race. Int J Sport Nutr Exerc Metab. 2008;18:152–68.
17. Enqvist JK, Mattsson CM, Johansson PH, Brink-Elfegoun T, Bakkman L, Ekblom BT. Energy turnover during 24 hours and 6 days of adventure racing. J Sports Sci. 2010;28(9):947–55.
18. Hulton AT, Lahart I, Williams KL, Godfrey R, Charlesworth S, Wilson M, Pedlar C, Whyte G. Energy expenditure in the Race Across America (RAAM). Int J Sports Med. 2010;31:463–7.
19. Zalcman I, Guarita HV, Juzwiak CR. Nutritional status of adventure racers. Nutrition. 2007;23:404–11.
20. Ganio MS, Klau JF, Casa DJ, Armstong LE, Maresh CM. Effect of caffeine on sports specific endurance performance: a systemic review. J Strength Cond Res. 2009;23(1):315–24.

Treatment of Casualties in Hostile Environments

8

Emergency Medicine in Mountain Sports

Fidel Elsensohn

8.1 Introduction

Rescue operations in mountains and remote areas are different from usual scenarios in urban areas. Topographical conditions, tactical considerations, medical equipment, and environmental conditions make mountain rescue operations a great challenge for the entire team.

In most European countries depending on the weather and visibility conditions, helicopters are activated in case of accidents or illness in the mountains. They are regularly equipped to cover all expectable technical and medical operations, and rescue personnel is trained according to international standards [1, 2] (Fig. 8.1).

Terrestrial rescue teams usually work in poor weather conditions and at night or when the airbound intervention teams need technical assistance. During rescue operations medical rescue personnel is frequently facing a hostile environment with cold, wet, windy, and low visibility conditions. In addition, the patient's condition can already deteriorate by delayed arrival time.

These circumstances complicate the initial assessment and diagnosis and limit medical treatment and outcome. Terrestrial rescue operations require extended activation time, high physical exertion, and environmental hazards during access to the site of the accident and prolonged evacuation time (Fig. 8.2).

Medical and technical management must be adapted to the conditions in order not to increase risk to the patient and the rescue team and to improve outcome. Monitoring may be restricted or not possible because devices are not always available and sometimes the weather conditions (freezing monitors), darkness, or certain injuries of the patient, for example, hypothermia, set limits for a continuous monitoring. All injured and sick persons in the mountains are considered hypothermic until the contrary is proved [3]. Further drop of body temperature should be avoided and assessment and treatment should avoid unnecessary undressing and provide proper insulation as soon as possible [4]. Physicians working in the mountains or mountainous environment must be comfortable in exposed situations, conscious of their own and the patient's safety, and being able to work under extreme conditions. Technical mountain knowledge and experience as well as theoretical and practical skill of climbing in steep terrain in summer and winter conditions are mandatory. Training for doctors must basically include the same technical skills like self-belaying and other rescue maneuvers, transport and management of avalanche victims, canyoning rescues, and other specific emergencies like regular training for all rescuers. Physicians as part of a helicopter crew frequently

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Fig. 8.1 Long-line operation

may be supported by a single (air) rescuer. Thus they must be trained in performing long-line or winch operations without the support of a team. In case of bad weather conditions, the physician must be able to move safely and descend by himself when necessary [5, 6] (Fig. 8.3).

Overall he should consider and accept that medical treatment may be limited and injuries usually survived in urban areas may lead to death in this setting. Despite intensive training, alpine emergency physicians constantly face the situation that mountain rescue personnel does not show the same high level of medical education as in urban emergency medical system, where usually professional staff provides emergency medical assistance [7]. In an urban setting different tasks are performed by professional health-care providers. In mountain rescue operations, emergency physicians must perform usually delegated measures by themselves. Nevertheless, they should not lose track of the overall situation and adapt medical care to the specific situation of the mission. Unnecessary and excessive medical measure ("stay and play") may delay the entire rescue operation unnecessarily and expose the patient and all team members to additional

Fig. 8.2 Terrestrial transport at night

Fig. 8.3 Long-line evacuation of patient

danger. In rescue operations risk assessment and management is one of the main tasks of the team leader. However, the emergency physician must adjust his actions to the situation and include the objective risk into his considerations. Emergency physician working in the mountains must adapt medical measures to existing human and technical resources. Optimized therapy should have priority over maximized treatment causing delay. Rapid evacuation may be an effective form of treatment. Every therapy, once begun, must be carried out until the patient is handed over to the following team. Adequate supply of medical or technical equipment, drugs, and oxygen is either not possible in reasonable time or might delay the entire rescue operation. Often the entire recovery cannot be brought later to the scene without delaying. In addition changing environmental factors and/or the patient's condition may force the emergency physician to employ alternative medical strategies or evacuation procedures in cooperation with the team leader. In extreme weather situations, it may be appropriate to stay with a medically stable patient in a safe place (hut or bivouac), until the situation allows terrestrial or air-bound evacuation. In mountain rescue the emergency physician is frequently not the first on the scene either because no doctor was available from the beginning or the first message about the severity of the injury or illness was not correct. In this situation the key question arises: can the patient be treated by first responders sufficiently and transported to the doctor? Or must the emergency physician ascend to the location of the accident? Assessment of symptoms and signs of injury severity can be performed by trained rescuers who act as first responders, and initial steps of treatment can be prioritized by radio or mobile phone. Evacuation time may be shortened, hazards reduced, and medical treatment will start earlier. Increasing numbers of mountaineers seek recreation in mountain regions where the existing rescue resources are far less and the problems much greater than in the situations as described above. Commonly rescuers reach the scene of the accident hours or days later, apart from the fact whether there are any technical and medical options for professional mountain rescue. Expedition medicine in high altitudes or in very remote mountainous areas is beyond the scope of this disquisition.

8.2 Assessment of Victims in the Mountains

In any emergency situation in the mountains, rescuers must first ensure their own safety. Then they must evaluate whether the person is in a safe position and protect him from further injury. Objective risks such as rockfall, avalanches, lightnings, etc., must be kept to a minimum. In dangerous situations it is justified to evacuate the person before assessment and treatment.

Blunt traumas caused by falls are most common in accidents in the mountains. They might affect all parts of the body and result often in combined or multiple trauma with hypovolemic shock and traumatic brain injury. The mechanism of injury gives information about the expected injury pattern and severity. High-impact mechanisms (falls from more than 3 m height) are likely to cause multiple trauma and internal injuries. The mechanism of injury of falls in the mountains is markedly different from falls in urban areas. Falls in mountainous terrain may include periods of free fall interrupted by periods of sliding and falling. The landing surface in the mountains is generally not horizontal in comparison to usually flat surface in urban falls. Impact forces may be reduced substantially by steep slopes or snow. Several impacts and different body positions may occur during the fall. Injuries may be caused by deceleration (resulting from tissue displacement following the sudden arrest of motion during impact) or direct impact-associated injuries [8]. Assessment should follow standardized algorithms and all findings should be recorded. Hypothermia is a severe risk and leads to poor outcome in severe trauma and must not be overlooked [9]. The patient should be monitored continuously, depending on the skills of rescuers and the availability of equipment. In extreme cold situations, monitoring systems may fail due to rapid loss of battery capacity and freezing displays. Every new team, which assumes care of a patient, must perform their own reassessment and must transfer information from earlier teams to following teams until the patient arrives at the hospital.

8.3 Hypothermia

Hypothermia is commonly assessed by clinical findings [10] (Table 8.1).

Patients should be considered to be hypothermic if they have been exposed to the cold and if they have a cold trunk and a body core temperature <35 °C (95 °F). Hypothermia can be diagnosed clinically by assessment of vital signs using the Swiss staging system. Temperature measurement in intubated patients in the preclinical setting should be measured by insertion of a probe in the lower third of the esophagus. Thermistor probes inserted in the ear canal for epitympanic measurement require a free ear canal without snow or cerumen. Infrared cutaneous, aural, and oral measurements are often inaccurate. It is of great importance to assess every

Table 8.1 Staging of hypothermia [10]

Swiss staging of hypothermia		
HT I	Clear consciousness with shivering	35–32 (°C)
HT II	Impaired consciousness without shivering	32–28
HT III	Unconsciousness	28–24
HT IV	Apparent death	24–15
HT V	Death due to irreversible hypothermia	<15 (9?)

hypothermic patient without vital signs, whether cardiac arrest occurred prior to hypothermia (postmortem cooling) or cardiac arrest is caused by hypothermia. At low temperatures the brain tolerates cardiocirculatory arrest much longer without permanent damage than in normal core temperature. Prehospital treatment of hypothermia should focus on careful handling, basic life support (BLS) or advanced life support (ALS), and external rewarming. Detecting a pulse or breathing in a patient with deep hypothermia may be difficult and should be performed over 1 minute. Every sign of life, like breathing movements, should prompt a watchful waiting and careful transport. In the absence of vital signs, cardiopulmonary resuscitation (CPR) should be started. Full body insulation with chemical heat packs provides a substantial amount of heat to prevent further heat loss. Conscious, shivering patients can be treated in the field. Patients with impaired consciousness but stable circulation require active external rewarming (blankets, forced air heating, or chemical or electrical heat packs) at the closest hospital. Patients with cardiac instability or cardiac arrest should be transported, favorable with helicopter, to a center with the ability of extra-corporal rewarming either with ECMO or cardiopulmonary bypass [3, 10, 11].

8.4 Lightning

In a continuing thunderstorm, evacuation of a victim might be postponed if there is a high risk for rescuers. If rescuers decide to perform a rescue operation, the victim should be moved as fast as possible to an area of lower risk. A person hit by a direct lightning strike in the open is dead in many cases. However, the most common cause of death is cardiorespiratory arrest produced by ventricular fibrillation or asystole caused by current splash either from an object nearby (e.g., tree), a contact with an object hit by a lightning (e.g., fixtures of a via ferrata), or a ground current. Blunt trauma may be caused by a shock wave and consecutive falls by loosing balance during climbing. Respiratory arrest may be prolonged (due to paralysis of the medullary respiratory center) and lead to secondary cardiac arrest from hypoxia. Spontaneous return of cardiac activity is the rule in this case if the patient's ventilation is maintained and severe hypoxia does not occur. In case of more than one victim hit by a lightning, the normal triage rules for trauma patients do not apply to non-breathing victims. In triage situations with trauma casualties, victims with vital signs are given priority for emergency treatment rather than patients in cardiorespiratory arrest. The rule in lightning strikes is to "resuscitate the apparently dead first" [12].

8.5 Trauma Management in Mountain Rescue Operations

Traumatic injuries are most common in mountain accidents. Approximately 10 % suffer from major trauma with traumatic brain injury (TBI) often in combination with injuries of the trunk, vertebral spine, pelvis, and extremities [8, 13]. Emergency physicians must consider the mechanism of injury to correctly assess pattern and severity of injuries, provide sufficient analgesia, stabilize circulation by control of external bleeding and adapted fluid resuscitation, and organize safe evacuation under constant surveillance and monitoring of the patient. Early pain treatment is not only for the comfort of the patient but allows repositioning of fractures and dislocations, reduces secondary damage to soft tissues, reduces bleeding, and is the first step of circulatory stabilization. Environmental conditions as well as psychological factors, comorbidities and time affect pain. Using a pain score, such as verbal numerical rating, can be helpful. Insufficient treatment of pain not only reduces outcome but also increases the development of post-traumatic stress disorder. Pervading culture and knowledge of health-care providers determine the provision of prehospital analgesia [14]. No analgesic drug will accomplish all expected effects in every situation. Non-pharmacological methods such as splinting and positioning should be taken in consideration especially by nonmedical personnel without the possibility of pharmacological pain treatment [15] (Fig. 8.4).

The number of drugs carried should be reduced to a minimum and tailored to the expected injuries and skills of the health-care provider. All persons administering analgesics should receive appropriate detailed training. Health-care providers should be familiar with the effects of all administered drugs and should be able to manage adverse effects. Sufficient pain relief might be constrained by national laws in countries where health-care professionals do not routinely attend the site of accident and nonprofessionals are not allowed to administer drugs [16]. An intravenous access should be established rapidly, and depending on pain assessment, a potent painkiller should be administered. If intravenous administration is not possible, other parenteral routes such as intraosseous and intramuscular routes may be utilized. Intranasal and buccal administration of opioids, ketamine, and sedative drugs is recommended in situations where no i.v. line can be established [17, 18]. Loco-regional anesthesia offers another way of excellent analgesia. It also may permit patient contribution during difficult and long evacuation or in high-altitude rescue [19, 20]. A combination of analgesic drugs is frequently used but a higher rate of side effects must be expected. Severe adverse effects such as respiratory depression, nausea, and vomiting can become hazardous during evacuation, especially in austere environment. Rescue population becomes older and comorbidities more common. Therefore,

Fig. 8.4 Rescue of injured patient in steep rock

analgesia should be individualized to each casualty, and preexisting drug use must be taken into consideration. Hypothermia alters the pharmacokinetics and pharmacodynamics of fentanyl, morphine, ketamine, and midazolam; especially the side effects of ketamine to an irritable hypothermic heart may be harmful [21]. Opioids remain the gold standard for pain management in acute trauma. Hypotension caused by significant blood loss may be limited by reduced initial dose given over a longer period of time [22] (Fig. 8.5).

Injuries with severe bleeding, traumatic brain injury (TBI), and multiple trauma require an individualized strategy for each patient. Traumatic shock during terrestrial mountain rescue operation, especially in uncontrolled bleeding and/or TBI, has a poor outcome. Aggressive fluid management in all cases failed to improve survival in

Technique/agent		Adult starting dose (dose in children)	Adult subsequent dosis	Comments contraindications
Opiods[1]				
Morphine				
	IV	5–10 mg* (100 mcg/kg) max 10 mg	5 mg	Avoid if renal failure
	IM	10–20 mg (200 mcg/kg) Max 10 mg)	10 mg	As above
	IO	5–10 mg* (100 mcg/kg) max 10 mg	5 mg	As above
Fentanyl				
	IV	50–100 mg* (1–3 mcg/kgmax 100 mcg)	25 mcg	Avoid if on monoamine oxidase inhibitors (MAOI)drugs
	IN	180 mcg* (1.5 mcg/kg)	60 mcg x2 (15 mcg x2)	As above
	Buccal	OTFC 800 mcg* (10–15 mcg/kg)		As above
Tramadol				
	IV	50–100 mg (700 mcg/kg) Over 2-3min	50 mg every 20 min max 600 mg/day	Avoid if on monoamine oxidase inhibitors (MAOI)drugs
NSAID				
Ketoralac				
	IV	15–30 mg (0.5 mg /kg, max 15 mg)	None	Avoid if risk of GI beeding and if current or past cardio- vascular disease
Others				
Paracetamol		>50 kg: - 1g; < 50 kg: - 15 mg/kg over 15 min		
Ketamin (for analgesia) halve if S-Ketamine is used				
	IV	10–20 mg* (100 mcg/kg)	5–20 mg	Larger dose for procedural sedation, Midazolam may be co-administered
	IM	1 mg/kg*	-	
	IN	0.5 mg/kg*	0.5 mg	
Inhalational				
Penthrox® Methoxyfluran				
	Inhaled	Self- administration 3 mL via inhaler	3 mL (max 6mL/day; 15 mL/week)	Avoid in renal impairment
50 % Nitrous oxide/50 % Oxygen				
	Inhaled	Self- administered		Avoid after SCUBA diving and when tension pneumothorax suspected. Maintain cylinder at 10 °C (50 °F)

* Consider halving in the elderly, frail and hemodynamically compromised

[1] Diamorphine, where available, is an alternative with the advantage that intranasal administration can be used

OTFC = oral transmucosal fentanyl citrate

Data from: Thomas (2008); Rickard (2007); Moy and Le Clerc (2011); Ellerton (2013); Royal Pharmaceutical Society of Great Britain and British Medical Association (2013); Finn and Harris (2010); Borland et al (2007); BOC Healthcare (2011)

Fig. 8.5 Recommended pharmacological agents for treating moderate or severe pain in mountain rescue [21] most studies [25–27]. Two decisive key conditions must be recognized in suspected major or multiple trauma: severe uncontrolled hemorrhage or presence of traumatic brain injury. Accurate diagnosing could be difficult as symptoms could be masked in the prehospital setting. Rapid deterioration or only transient responding circulatory parameters under initial fluid resuscitation could be caused by pressure-depending hemorrhage. Increasing impaired consciousness may be caused by traumatic brain injury but also by arterial hypotension, hypoxemia, cardiac dysfunction, and hypothermia. Mechanism of injury (e.g., high-velocity trauma) and/or external signs of head injury, anisocoria, and a Glasgow Coma Scale (GCS) below 9 are strong indicators for TBI (Fig. 8.6).

Terrestrial mountain rescue operations in patients with multiple trauma and shock are often characterized by prolonged evacuation time and hostile environment. Reduced diagnostic and monitoring facilities, limited oxygen fluids, and drugs make any medical intervention difficult. Different strategies of prehospital fluid resuscitation are practiced in different regions worldwide, and none of these concepts support them beyond any scientific doubt. Systolic arterial blood pressure (SABP) ≤90 mmHg in trauma may decrease outcome. But in uncontrolled severe hemorrhage (e.g., liver, spleen, and kidney lacerations or ruptured vessels), aggressive fluid resuscitation may increase bleeding and does not show any increase in outcome [27]. Withholding fluid ("delayed resuscitation") or limiting fluids with aimed blood pressure to just maintain consciousness and/or palpable central pulse (indicating an SABP above 60 mmHg) ("permissive hypotension") may be a better option for patients in traumatic shock even in prolonged evacuation [28].

In these cases rapid evacuation and transport in combination with sufficient analgesia are the key to improve outcome, and medical interventions should follow the principle: "Load and Go." Rapid transport may be considered as one form of treatment [29].

If traumatic brain injury or a spinal lesion is suspected, the main goal for prehospital treatment is SABP higher than 110 mmHg in order to ensure adequate perfusion of the central nervous system (Fig. 8.7). Rapid elevation of blood pressure can be achieved by administration of hypertonic solutions followed by isotonic fluids. Catecholamine may be advantageous. After establishing intravenous or intraosseous access airway protection by endotracheal intubation or laryngeal tubes, high flow of oxygen (if available) should follow. Sufficient analgesia is mandatory as it may reduce sympathetic stimulation

Fig. 8.6 Terrestrial rescue at night

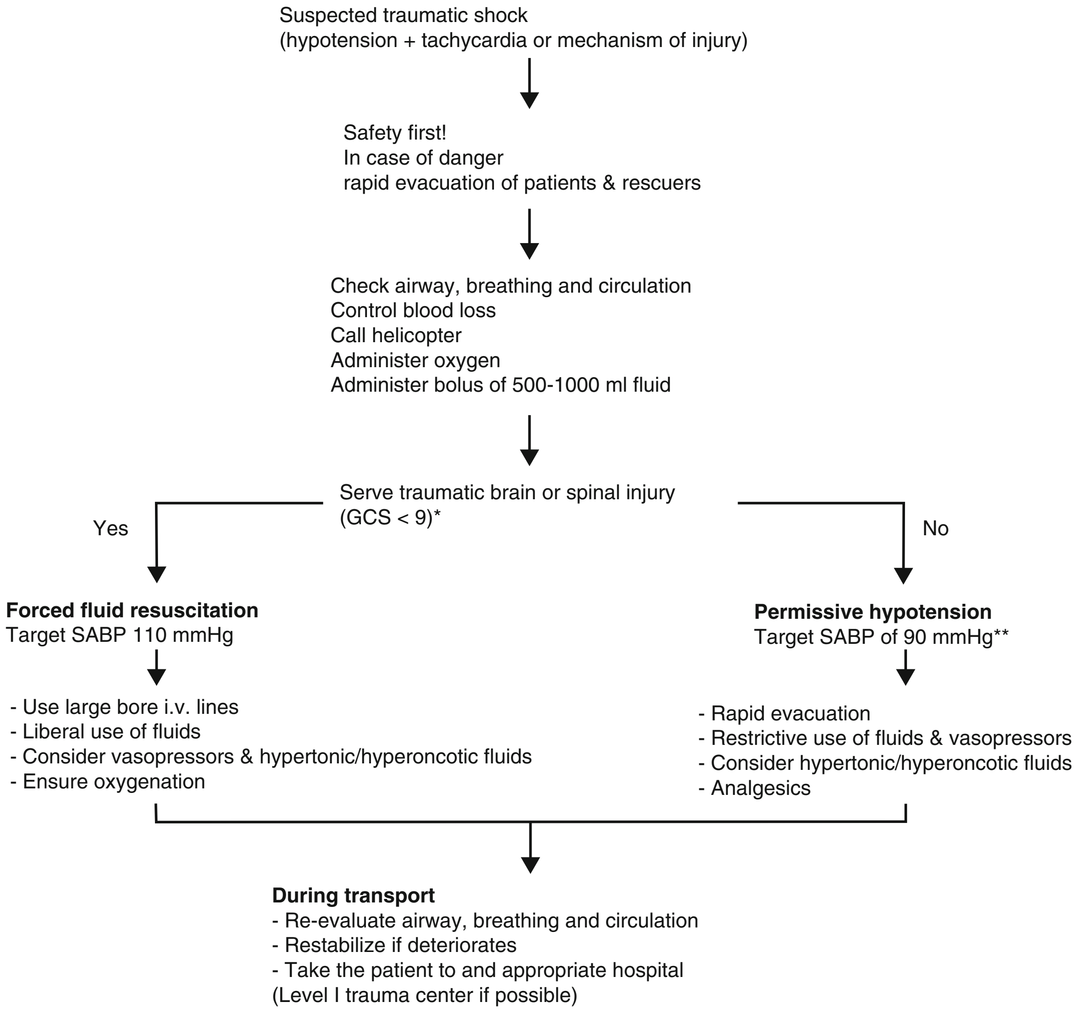


Fig. 8.7 Fluid management in traumatic shock. A protocol for the prehospital management of patients in traumatic shock with or without brain or spinal injury in mountainous terrain and remote areas. Impairment of consciousness does not necessarily indicate severe TBI in a shock patient; hypoxia, tension pneumothorax, cardiac dysfunction, and hypothermia should be excluded. If uncontrolled hemorrhage is suspected, lower values maintaining consciousness and/or palpable central pulses may be reasonable. *GCS* Glasgow Coma Scale, *SABP* systolic arterial blood pressure [23, 24]

and hasten evacuation. During transport frequent reassessment of reestablishment of breathing (e.g., deflating a tension pneumothorax) and circulation must take place, and an alternative strategy of fluid resuscitation may be considered. Besides fluid administration control of blood loss by wound management, repositioning, and splinting and prevention of hypothermia is essential [30, 31]. Hypothermic patients in traumatic shock and cerebrospinal injury are prone to hypothermia due to destabilized thermoregulation. Hypothermia increases bleeding by reduced platelet function and consecutive critical coagulopathy below 34 °C with reduced outcome [9, 32].

All patients should be transported to an appropriate trauma center without delay if possible with helicopters [33]. Multiple trauma in combination with TBI in the mountains or remote areas shows poor outcome when compared to urban areas, and urban traumatic shock protocols may not apply in all situations.

8.5.1 Prehospital Treatment of Avalanche Victims

Approximately 150 people die on avalanches per year in Europe and North America [34]. In less developed countries, fatalities are presumed to be many times higher. If a person is caught by an avalanche, four factors are decisive for survival: grade of burial, duration of burial, presence of an air pocket and a free airway, and severity of trauma. The overall mortality is 23 % but in completely buried victims (head below snow) it is 52 % and only 4 % if the head is not covered. In completely buried victims, survival drops from 80 % after the first 20 min to 30 % at 35 min. Initial mortality is mainly caused by trauma, whereas the steep decline between 20 and 35 min is due to asphyxia. After this period, survival is decreasing slower depending on trauma and the possibility to breathe under the snow. Limiting factors in this period are hypoxia, hypercapnia, and hypothermia [35]. Decline of survival seems to be affected by snow density resulting in lower survival rate in Canada compared to Swiss findings representing the situation in the Alps [36] (Figs. 8.8 and 8.9).

Avalanche survival is strongly time dependent. Therefore, immediate search and excavation performed by companions may be lifesaving. As soon as the head is free, assessment of airway and breathing and if necessary cardiopulmonary resuscitation (CPR) must be started and maintained until return of spontaneous circulation (ROSC) or a professional rescue team takes over. The victim's body must be protected from the cold by insulation with all available materials such as rescue blanket, jackets, hat, gloves, and bivouac bag [35].

Organized rescue in Europe is mainly based on helicopter rescue. In good weather conditions, a fully equipped and staffed rescue helicopter should be activated without delay [1] (Fig. 8.10).

An avalanche rescue team might incur critical risk, and therefore the expected benefit to the victim must be weighed against the risk to the rescue team. Several accidents with numerous fatalities among rescue teams the last few years strongly indicate accurate risk assessment. All rescuers working on-site of the avalanche must be equipped with avalanche transceivers, probes,

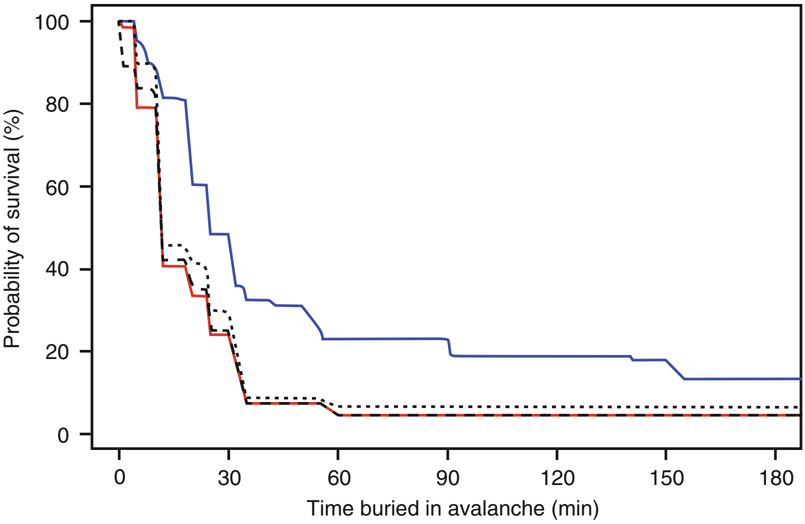


Fig. 8.8 Avalanche Survival Curve. Comparison of survival curves: Swiss survival curve (*blue*; $n = 946$) and Canadian survival curve (*red*; $n = 301$). The black dotted survival curve is based on the Canadian dataset without trauma fatalities ($n = 255$). The *black dashed* survival curve is calculated with the Canadian dataset where the extraction times for severe trauma fatalities was replaced with an estimated time of death of 1 minute after burial ($n = 301$) (From: Haegeli et al. [36])

Fig. 8.9 Evacuation of injured person

Fig. 8.10 Preparing rescue dog for search mission

shovels, and ideally with avalanche airbags. Optimal searching strategy, rapid locating of victims with transceivers, and effective shoveling are mandatory to reduce burial time. Located victims should receive immediate assessment and adapted treatment according to clinical findings. ECG monitoring and core temperature measurement should already start when the head and trunk is free. Extricated patients must be protected from hypothermia by full body insulation including chemical heat packs, aluminum foils, and thermo rescue bags. Further treatment is depending on the cardiorespiratory situation and body core temperature.

In patients found in cardiac arrest with clear signs of lethal trauma or if the chest or abdomen is not compressible or if transport with continuous CPR presents a high risk to the rescuers, resuscitation is not indicated [37].

If duration of burial exceeds 60 minutes, a patent airway is the key for survival and prevention of further heat loss and treatment of hypothermia is essential. Consciousness varies widely among hypothermic patients. Therefore, early measurement of core temperature should be performed immediately either by thermistor-based probes in the ear canal. In intubated patients esophageal probes are the gold standard. All patients should receive cardiac monitoring prior to transport to detect arrhythmias provoked by movement of the body during extrication. In hypothermic patients pulse oximetry is not reliable. Establishing an i.v. line may be difficult and time consuming in hypothermic patients, and aggressive fluid resuscitation is contraindicated in deep hypothermia. ALS drugs should only be administered only in normothermic avalanche victims. In victims with core temperature below 30 °C, effectiveness of advanced life support drugs has not been shown due to decreased metabolism. Vasopressors may cause arrhythmias and frostbites. Hypothermic patients in ventricular fibrillation should receive three attempts of defibrillation if it does not delay or interrupt transport [3].

8.5.2 Resuscitation of Completely Buried Avalanche Victims [38–42]

- *Patient alert and shivering, burial time <60 minutes*
- Prevention of hypothermia by changing wet clothes if appropriate. Patient is allowed to drink nonalcoholic warm drinks and walk and should be transported to the nearest hospital for observation.
- *Patient in cardiac arrest, burial time <60 minutes*
- Traumatic brain injury or asphyxia should be presumed and standard ALS should be performed. If possible the patient should be transported to the nearest hospital.
- *Patient somnolent or comatose but breathing, burial time >60 minutes*
- Prehospital treatment focuses on adequate oxygenation, careful handling and avoiding movements of the patient, and full body insulation including chemical heat packs on the trunk to prevent further cooling. In this situation speed is not the main task. Gentle handling and a horizontal position may avoid afterdrop and rescue collapse due to arrhythmias. If the airway is not secured, the patient should be placed in recovery position. Endotracheal intubation or supraglottic airway devices protect the airway in unconscious or unresponsive patients. Prolonged assessment and treatment should be avoided to prevent further heat loss, and the patient should be transported, favorable with helicopter, to a hospital with intensive care unit experienced in treatment or severe hypothermia (Fig. 8.11).
- *Patient in cardiac arrest, obstructed airway, and burial time >60 minutes*
- Resuscitation may be started but may be terminated if not successful.
- *Patient not breathing (cardiac arrest), patent airway, and burial time >60 minutes*

Fig. 8.11 Long-line evacuation of patient in winter conditions

- Precise detecting vital signs may be difficult. If the airway is patent, all patients should be directly transported to a hospital capable of extracorporeal rewarming either with cardiopulmonary bypass or extracorporeal membrane oxygenation (ECMO). CPR should follow standard algorithms. Defibrillations are usually not successful in severe hypothermia, but three attempts may be tried if transport is not delayed. Unsuccessful defibrillation must not lead to termination of CPR as there are many case reports with full recovery after prolonged CPR followed by rewarming. Mechanical chest-compression devices increase the effectiveness of prolonged CPR not only terrestrial but also during helicopter transport. If transport to a hospital with extracorporeal rewarming is not possible, the patient may be brought to the next hospital and serum potassium may be used as additional prognostic marker. Serum potassium level <8 mmol/L presents a good chance for ROSC. Higher values may be considered as reason for termination of CPR. The main principle of avalanche rescue should be: “No hypothermic avalanche victim with a patent airway is dead until warm and dead” (Figs. 8.12 and 8.13).

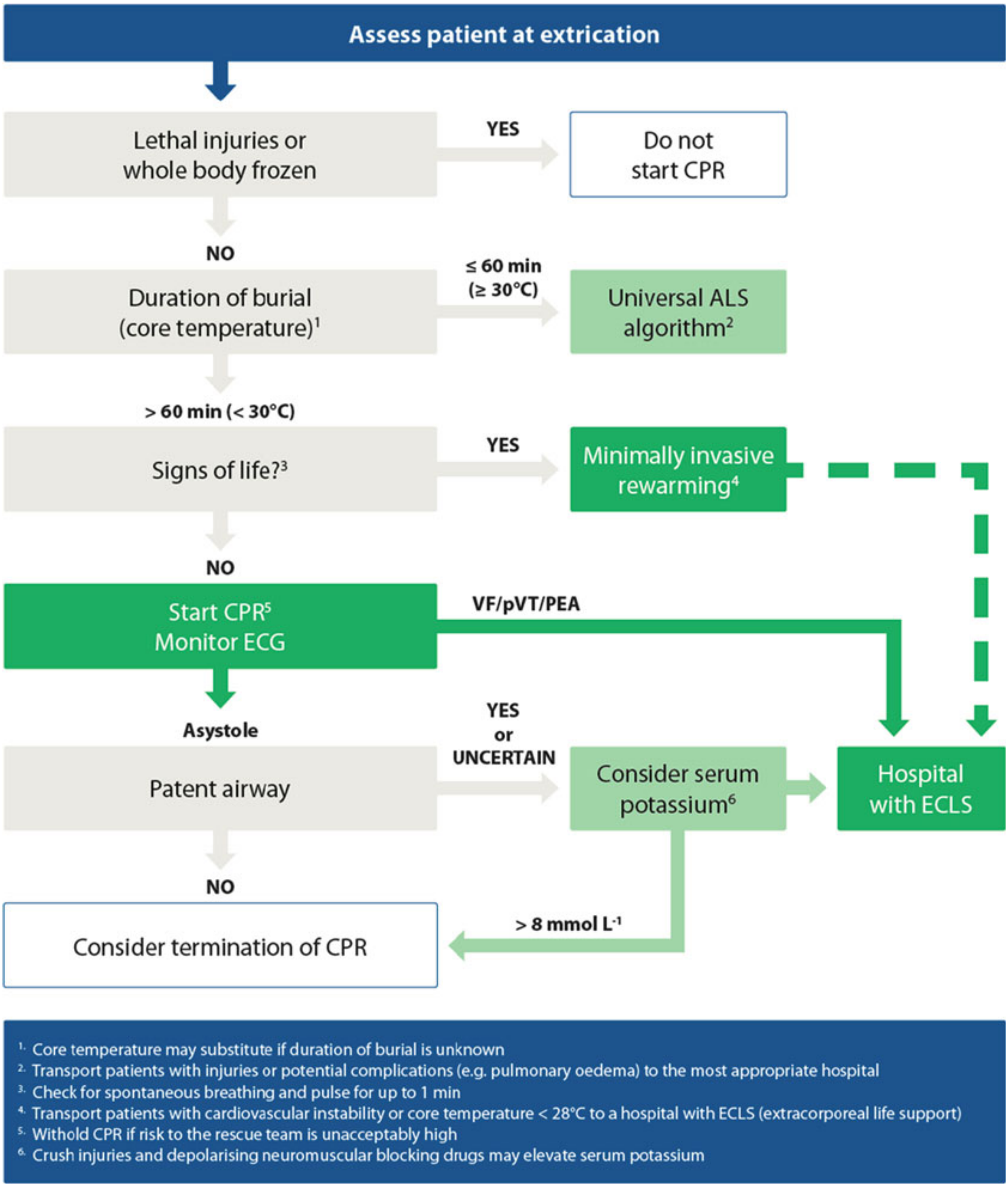
8.5.3 Suspension Trauma

Suspension trauma is a usual pathophysiological reaction to the body in motionless upright position. After a short time, blood begins to pool in the lower part of the body and the patient may faint. Continuous suspension in this motionless upright position unable to fall over may cause cardiac arrest. Urgent removal and adequate medical care may prevent death. Though the exact pathophysiological mechanism is not clearly explained, different medical strategies have been reported. Keeping the patient’s upper body in upright position was considered as an important measure to prevent rescue death and supported by current guidelines. However, there is no clear scientific evidence that this procedure may prevent healthy subjects from death exposed to suspension trauma. Whether death is caused by cardiac arrhythmia or acute heart failure due to volume overload is still unknown. Victims suffering from suspension trauma are generally healthy young people. In many other situations, patients with acute cardiac failure (anaphylaxis, traumatic hypovolemia, vasovagal syncope, etc.) are treated with volume replacement in supine position following ALS guidelines. Securing the airway, breathing, and circulation are the important initial steps in managing unconscious and/or traumatized patients. Assessment and treatment are generally performed in horizontal position because it may be challenging in upright position. Prehospital diagnosis of hypovolemia and reduced central venous return may be difficult; nevertheless fluid resuscitation following established guidelines should not be delayed [43, 44].

Fig. 8.12 Preparing hypothermic patient for transport

8.6 Medical Equipment in Mountain Rescue

Medical equipment in mountain rescue is usually carried in backpacks. They should be equipped according to national laws and cover typical medical emergencies in a certain region taking into account climate, geography, and medical skills of the rescue personnel. Automated external defibrillators (AEDs) should be part of this equipment when afford-



[1] Core temperature may substitute if duration of burial is unknown
[2] Transport patients with injuries or potential complications (e.g. pulmonary oedema) to the most appropriate hospital
[3] Check for spontaneous breathing and pulse for up to 1 min
[4] Transport patients with cardiovascular instability or core temperature < 28°C to a hospital with ECLS (extracorporeal life support)
[5] Withold CPR if risk to the rescue team is unacceptably high
[6] Crush injuries and depolarising neuromuscular blocking drugs may elevate serum potassium

Fig. 8.13 Avalanche management algorithm [40]

able [45]. In many organizations rescue strategies follow the principle of one rapidly ascending team (first responders) with reduced technical and medical equipment and the main team providing all redundant support later. In some countries like North America, Canada, and the United Kingdom, paramedics, emergency medical technician, or certified mountain rescuers act as first responders who are able to administer a restricted range of drugs.

Table 8.2 Recommendation for mountain rescuer's medical backpack [47]

Drugs
Drugs
According to national and internal regulations, e.g., nonsteroidal anti-inflammatory drug (e.g., acetylsalicylic acid, diclofenac, ketoprofen), morphine, nitroglycerin
Medical equipment
I.v. line
Intravenous line set and infusions (e.g., 500 mL crystalloid-fluid)
Miscellaneous equipment
Adhesive tape, aluminum blanket, gloves, scissors
Monitoring
Blood pressure measurement, pulse oximetry, thermometer epitympanic
Trauma
Splinting (e.g., cervical collar, SAM splint®), wound dressing
Ventilation
Bag valve mask, manual suction device, nasopharyngeal and oropharyngeal tube, oxygen, pocket mask ®, venturi mask

Medical equipment transported to a casualty should be limited to the most essential items, because weight is premium in helicopter emergency medical services and in terrestrial rescue where it has to be carried often over a prolonged time [2].

Most mountain rescue teams have divided their medical backpacks into one for trained mountain rescuers and one for physicians tailored to the different tasks and skills. Backpacks for rescuers (first responders) should contain equipment for BLS, splinting, wound dressing, blood pressure, and hypothermia treatment. Oxygen is an important drug in prehospital care but the weight may slow down the first team. Ventilation by rescuers should be performed with mouth-to-mask ventilation [46]. Acceptance is high because handling is simple, safe, and effective. New small AEDs with monitoring function can be considered in order to complete cardiorespiratory assessment. Findings may be reported to the physician (telemetric data transmission in the future?), and advice may be given via radio (Table 8.2).

Backpacks for physicians should cover ALS, treatment of trauma, anaphylaxis, pulmonary disorders, and hypertensive urgencies. Drugs should be selected by the physician according to his experience. He should only administer drugs which he is familiar with and able to manage potential adverse effects.

In order to save weight, the rescuers' and physicians' backpacks should be complementary, and repeated training in the use and maintenance is mandatory [6]. Backpacks for rescuers usually weigh 5–8 kg and physicians' backpacks approximately 12–20 kg including all recommended items [47] (Table 8.3).

8.7 Termination of Resuscitation

Rescuers and physicians in the mountains are regularly confronted with lifeless persons either when rescuers arrive at the scene of accident prior to a physician or a physician is confronted with a lifeless person without the possibility of technical diagnosis of death (e.g., ECG). The decision to resuscitate may increase the risk for rescuers as initiation of resuscitation and extrication need to be started in dangerous terrain under extreme climate conditions. Several fatal accidents involving mountain rescuers in the line of duty during the past years demanded the establishment of guidelines in order to reduce unnecessary CPR [37]. This may not only reduce the risk for rescuers but also avoid unnecessary transport and direct limited resources to those patients who have a chance of survival [1, 6, 7, 47].

Resuscitation rules validated for resuscitation in urban areas may not be applicable for situations in the mountains. The 2012 American Heart Association guidelines recommend CPR performed by BLS providers should be continued until return of spontaneous circulation (ROSC), care is transferred to an ALS team, and rescuers are exhausted or CPR would jeopardize rescuers or others or reliable criteria for death are not met or criteria for termination of

Table 8.3 Recommendations for a physician's backpack in mountain rescue [47]

Drugs
ALS
Amiodarone, atropine, epinephrine
Analgetics
Strong opioid (e.g., fentanyl, morphine), ketamine; nonsteroidal anti-inflammatory drug (e.g., diclofenac, ketoprofen)
Sedatives
Etomidate, midazolam, propofol
Muscle paralytics
Rocuronium, suxamethonium
Cardiovascular drugs
Acetylsalicylic acid, beta-blocker, fibrinolytic, heparin, nitroglycerin, vasopressor (e.g., dopamine, norepinephrine)
Bronchodilators
Beta-agonists (inhalative and i.v.), corticosteroids (inhalative), theophylline
Other drugs
Flumazenil, furosemide, glucose 33 or 40 %, H_1- and H_2-receptor antagonists, naloxone, corticosteroids (i.v.)
Medical equipment
I.v. line
Intravenous line set and infusions (e.g., 500 mL crystalloid), hypertonic fluid
Miscellaneous equipment
Adhesive tape, aluminum blanket, gloves, indwelling urinary catheter and bag, scissors
Monitoring
Blood pressure measurement, capnography, electrocardiogram, glucometer, pulse oximetry, stethoscope, thermometer esophageal and epitympanic
Trauma
Replantation bag, splinting (e.g., cervical collar, SAM splint®), wound dressing
Ventilation
Alternative airway device (e.g., laryngeal mask), bag valve mask, manual suction device, nasopharyngeal and oropharyngeal tube, oxygen, thoracotomy set, tracheal intubation set (plastic laryngoscope scoop preferable with cold weather), venturi mask

ALS denotes advanced life support

resuscitation are not met [48]. These rules are promising but should be applied cautiously in mountain rescue. In mountain and wilderness area, circumstances for cardiac arrest and survival may be different and unexpected survival may be possible [49]. A modified BLS termination of resuscitation guideline established in 2012 by the International Commission for Mountain Emergency Medien (ICAR MEDCOM) should limit unappropriate CPR in mountain rescue. In case of unwitnessed cardiac arrest and no spontaneous return of circulation during 20 minutes of CPR and no shock advised at any time by AED or only asystole observed by ECG and no hypothermia or other special circumstances warranting extended CPR, CPR may be terminated. In case of witnessed cardiac arrest or if one of the above criteria is absent, CPR should be continued until qualified medical personnel performing clinical assessment of the patient, situation, CPR, and transportation factors determines that further CPR is futile. Frequently reported cases of ROSC after prolonged resuscitation using mechanical chest compression devices give hope in special circumstances and emphasize

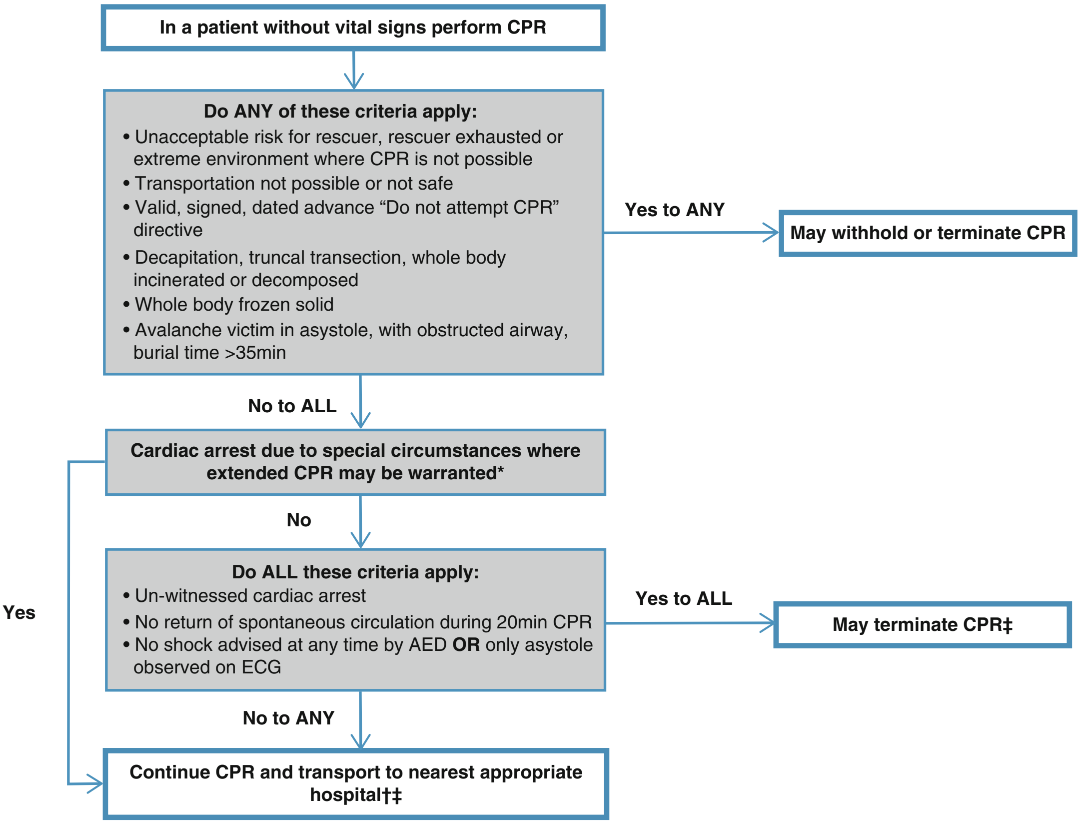


Fig. 8.14 Termination of resuscitation

the need of accurate assessment. However, prolonged CPR is not indicated when a patient is not expected to survive, consistent with the principle of medical futility or when the resources of rescuers are inadequate or excessive long transport is expected (Fig. 8.14) [48].

Conclusion

Emergency medicine in mountains and remote areas requires high physical and technical skills by rescuers and physicians. Assessment and treatment may be limited due to hostile environmental conditions and rapid deterioration of patients caused by delayed treatment and prolonged evacuation time. Hypothermia is common in mountain casualties, should not be overlooked, and accurately treated. Trauma treatment is based on sufficient pain relief and adapted fluid resuscitation. Avalanche victims have a great chance of survival if extricated within 15–20 min. Survival longer than 60 minutes in totally buried victims is dependent on a patent airway. On-site treatment and transport should focus on immediate CPR, prevention of hypothermia, and rapid transport to an appropriate hospital. Medical equipment in mountain rescue needs to be adapted to the expected scenario of injury and the skills of rescuers and physicians. In special circumstances withholding or terminating CPR may reduce the risk for rescue teams and save human and technical resources (Fig. 8.15).

Fig. 8.15 Longline operation in winter

Acknowledgment This chapter is based on recommendations and guidelines established by ICAR MEDCOM (International Commission for Mountain Emergency Medicine), a subcommission of the International Commission for Alpine Rescue (ICAR: www.alpine-rescue.org). ICAR is the worldwide platform for the exchange of experience and knowledge in mountain rescue. ICAR MEDCOM consists of over 60 members, experienced active mountain emergency physicians delegated from almost 40 organizations worldwide. All recommendations and guidelines are published in peer-reviewed medical journals. Together with the International Society for Mountain Medicine (ISMM) and the Medical Commission of the International Mountaineering and Climbing Federation (UIAA MEDCOM), ICAR MEDCOM has established curricula for the "International Diploma in Mountain Medicine" and the "International Diploma in Mountain Emergency Medicine."

References

1. Tomazin I, Ellerton J, Reisten O, Soteras I, Avbelj M. Medical standards for mountain rescue operations using helicopters: Official consensus recommendations of the International Commission for Mountain Emergency Medicine (ICAR MEDCOM). High Alt Med Biol. 2011;12:335–41.
2. Tomazin I, Kovacs T. Medical considerations in the use of helicopters in mountain rescue. High Alt Med Biol. 2003;4:479–83.
3. Brown D, Brugger H, Boyd J, Paal P. Accidental hypothermia. N Engl J Med. 2012;367:1930–8.
4. Søreide K. Clinical and translational aspects of hypothermia in major trauma patients: From pathophysiology to prevention, prognosis and potential preservation. Injury. 2014;45(4):647–54. doi:10.1016/j.injury.2012.12.027.
5. Elsensohn F, editor. Consensus guidelines in mountain emergency medicine and risk reduction. Lecco: Casa Editrice Stefanoni; 2002.
6. Elsensohn F, Niederklapfer T, Ellerton J, Swangard M, Brugger H, Paal P. Current status of medical training in mountain rescue in America and Europe. High Alt Med Biol. 2009;10:195–200.
7. Brugger H, Elsensohn F, Syme D, Sumann G, Falk M. A survey of emergency medical services in mountain areas of Europe and North America: Official recommendations of the International Commission for Mountain Emergency Medicine (ICAR Medcom). High Alt Med Biol. 2005;6:226–37.

8. Hohlrieder M, Eschertzhuber S, Schubert H, Zinnecker R, Mair P. Severity and pattern of injury in alpine fall accidents. High Alt Med Biol. 2004;3: 349–54.
9. Wang HE, Callaway CW, Peitzman AB, Tisherman SA. Admission hypothermia and outcome after major trauma. Crit Care Med. 2005;33:1296–301.
10. Durrer B, Brugger H, Syme D. International Commission for Mountain Emergency Medicine. The medical on-site treatment of hypothermia: ICAR-MEDCOM recommendation. High Alt Med Biol. 2003;4:99–103.
11. Walpoth BH, Walpoth-Aslan BN, Mattle HP, et al. Outcome of survivors of accidental deep hypothermia and circulatory arrest treated with extracorporeal blood warming. N Engl J Med. 1997;337:1500–5.
12. Zafren K, Durrer B, Herry JP, Brugger H. Lightning injuries: Prevention and on-site treatment in mountains and remote areas. Official guidelines of the International Commission for Mountain Emergency Medicine and the Medical Commission of the International Mountaineering and Climbing Federation (ICAR and UIAA MEDCOM). Resuscitation. 2005;65:369–72.
13. Hearns S. The Scottish mountain rescue casualty study. Emerg Med J. 2003;20:281–4.
14. Ellerton J, Paal P, Milani M, Blancher M, Zen-Ruffinen G, Skaiaa SV, Brink B, Lohani A. Managing moderate and severe pain in Mountain Rescue: official recommendations of the International Commission for Mountain Emergency Medicine, ICAR MEDCOM. Intended for Mountain Rescue First Responders, Nurses, Paramedics, Physicians, and Rescue Organizations. Mary Ann Liebert, Inc. High Alt Med Biol. 2014;15(1):8–14. doi:10.1089/ham.2013.1135.
15. Ellerton J, Tomazin I, Brugger H, Paal P. Immobilization and splinting in mountain rescue. High Alt Med Biol. 2009;10:337–42.
16. Ellerton JA, Greene M, Paal P. The use of analgesia in Mountain rescue casualties with moderate or severe pain. Emerg Med J. 2013;30:501–5.
17. Castner T. Endonasale Applikation von Notfallmedikamenten. Rettungsdienst. 2005;9:26–9.
18. Rickard C, O'Meara P, McGrall M, Garner D, McLean A, Le Lievre P. A randomized controlled trial of intranasal fentanyl vs intravenous morphine for analgesia in the prehospital setting. Am J Emerg Med. 2007;25:911–7.
19. Gros T, Viel E, Ripart J, Delire V, Eledjam JJ, Sebbane M. Prehospital analgesia with femoral nerve block following lower extremity injury. [Article in French]. A 107 cases survey. Ann Fr Anesth Reanim. 2012;31:846–9.
20. Lopez S, Gros T, Bernard N, Plasse C, Capdevila X. Fascia iliaca compartment block for femoral bone fractures in prehospital care. Reg Anesth Pain Med. 2003;28:203–7.
21. Ellerton J, Paal P, Brugger H. Prehospital use of ketamine in mountain rescue. Emerg Med J. 2009;26: 760–1.
22. Smith MD, Wang Y, Cudnik M, Smith DA, Pakiela J, Emerman CL. The effectiveness and adverse events of morphine versus fentanyl on a physician-staffed helicopter. J Emerg Med. 2012;43:69–75.
23. Nolan J. Fluid resuscitation for the trauma patient. Resuscitation. 2001;48:57–69.
24. Sumann G, Paal P, Mair P, Ellerton J, Dahlberg T, Zen-Ruffinen G, Zafren K, Brugger H. Fluid management in traumatic shock: A practical approach for mountain rescue. Official recommendations of the International Commission for Mountain Emergency Medicine(ICAR MEDCOM). High Alt Med Biol. 2009;10:71–5.
25. Roberts I, Evans P, Bunn F, Kwan I, Crowhurst E. Is the normalisation of blood pressure in bleeding trauma patients harmful? Lancet. 2001;357:385–7.
26. Riddez L, Johnson L, Hahn RG. Central and regional hemodynamics during crystalloid fluid therapy after uncontrolled intra-abdominal bleeding. J Trauma. 1998;44:433–9.
27. Krausz MM, Bashenko Y, Hirsh M. Crystalloid and colloid resuscitation of uncontrolled hemorrhagic shock following massive splenic injury. Shock. 2001;16:383–8.
28. Kreimeier U, Lackner CK, Pruckner S, Ruppert M, Peter K. Permissive hypotension in severe trauma. Anaesthetist. 2002;51:787–99.
29. Pepe PE, Mosesso VN, Falk JL. Prehospital fluid resuscitation of the patient with major trauma. Prehosp Emerg Care. 2002;6:81–91.
30. Voeickel WG, Von Goedecke A, Fries D, Krismer AC, Wen-zel V, Lindner KK. Treatment of hemorrhagic shock. New therapy options. Anaesthetist. 2004;53:1151–67.
31. Soreide E, Deakin CD. Pre-hospital fluid therapy in the critically injured patient: A clinical update. Injury. 2005;36:1001–10.
32. Rajagopalan S, Mascha E, Na J, Sessler DI. The effects of mild perioperative hypothermia on blood loss and transfusion requirement. Anesthesiology. 2008;108:71–7.
33. Härtl R, Gerber LM, Iacono L, Ni Q, Lyons K, Ghajar J. Direct transport within an organized state trauma system reduces mortality in patients with severe traumatic brain injury. J Trauma. 2006;60(6):1250–6.
34. Etter HJ. Report of the avalanche subcommission at the general meeting of the international commission for alpine rescue. 2010.
35. Brugger H, Durrer B. On-site treatment of avalanche victims ICAR-MEDCOM- recommendation. High Alt Med Biol. 2002;3:421–5.
36. Haegeli P, Falk M, Brugger H, Etter HJ, Boyd J. Comparison of avalanche survival patterns in Canada and Switzerland. CMAJ. 2011;183:789–95. doi:10.1503/cmaj.101435.
37. Paal P, Milani M, Brown D, Boyd J, Ellerton J. Termination of cardiopulmonary resuscitation in mountain rescue. High Alt Med Biol. 2011;13(3): 200–8.

38. Brugger H, Durrer B, Elsensohn F, Paal P, Strapazzon G, Winterberg E, Zafren K, Boyd J. Resuscitation of avalanche victims: Evidence-based guidelines of the international commission for mountain emergency medicine (ICAR MEDCOM). Intended for physicians and other advanced life support clinicians. Resuscitation. 2013;84(5):539–46.
39. Boyd J, Brugger H, Shuster M. Prognostic factors in avalanche resuscitation: A systematic review. Resuscitation. 2010;81:645–52.
40. Truhlar A, Deakin C, Soar J, et al. European Resuscitation Council Guidelines for Resuscitation 2015; Section 4. Cardiac arrest in special circumstances: Resuscitation. 2015;95:148–201.
41. Mair P, Kornberger E, Furtwaengler W, Balogh D, Antretter H. Prognostic markers in patients with severe accidental hypothermia and cardiocirculatory arrest. Resuscitation. 1994;27:47–54.
42. Soar J, Nolan J, Böttiger B, et al. European Resuscitation Council Guidelines for Resuscitation 2015 Section 3. Adult advanced life support. Resuscitation. 2015;95:100–47.
43. Mortimer R. Risks and management of prolonged suspension in an alpine harness. Wilderness Environ Med. 2011;22:77–86.
44. Homassen O, Skaiaa SC, Brattebo G, Heltne JK, Dahlberg T, Sunde GA. Does the horizontal position increase risk of rescue death following suspension trauma? Emerg Med J. 2009;26:896–8.
45. Elsensohn F, Agazzi G, Syme D, Swangard M, Facchetti G, Brugger H. The use of automated external defibrillators and public access defibrillators in the mountains: Official guidelines of the international commission for mountain emergency medicine ICAR-MEDCOM. Wilderness Environ Med. 2006; 17:64–6.
46. Paal P, Ellerton J, Sumann G, Demetz F, Mair P, Brugger H. Basic life support ventilation in mountain rescue. Official recommendations of the International Commission for Mountain Emergency Medicine (ICAR MEDCOM). High Alt Med Biol. 2007; 8:147–54.
47. Elsensohn F, Soteras I, Reisten O, Ellerton J, Brugger H, Paal P. Equipment of medical backpacks in mountain rescue. High Alt Med Biol. 2011; 12(4):343–7.
48. Morrison LJ, Kierzek G, Diekema DS, Sayre MR, Silvers SM, Idris AH, Mancini ME. Part 3: Ethics: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation. 2010;122:665–75.
49. Strapazzon G, Beikircher W, Procter E, Brugger H. Electrical heart activity recorded during prolonged avalanche burial. Circulation. 2012;125:646–7.

9 Drug Abuse, Doping, and Extreme Sports

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9.1 Definition

Doping in sport is defined as voluntary or involuntary use of prohibited substances or methods. The World Anti-Doping Code is a set of rules that was created to harmonize anti-doping efforts. The Code has been accepted by all international Olympic sport federations, Olympic and paralympic committees, and many other sport organizations. It was implemented from 1 January 2004 (revised 1 January 2009). Among signatories are federations such as the World Triathlon Corporation, Confédération mondiale des activités subaquatiques, or International Mountaineering and Climbing Federation [1].

The Code is closely related to five international standards which set up rules in testing, laboratories, Therapeutic Use Exemptions, the List of Prohibited Substances and Methods, and privacy protection.

A substance/method is placed on the list when it has the potential to enhance or enhances sport performance, it poses a health risk for the athlete, or it is contrary to the spirit of the sport.

An updated List of Prohibited Substances and Methods is announced every year on the website of the World Anti-Doping Agency. It comprises substances prohibited at all times (in and out of competition): S0, non-approved substances; S1, anabolic agents; S2, peptide hormones, growth factors, and related substances; S3, beta-2 agonists; S4, hormone and metabolic modulators; and S5, diuretics and other masking agents.

Among methods forbidden at all times are M1, manipulation of blood and blood components; M2, chemical and physical manipulation; and M3, gene doping. To substances and methods prohibited in competition belong S6, stimulants; S7, narcotics; S8, cannabinoids; and S9, glucocorticosteroids. Alcohol (P.1) and beta-blockers (P.2) are banned in particular sports.

In the list of adverse analytical findings and atypical findings reported by WADA-accredited laboratories in 2012, the most frequent ones were as reported in Table 9.1 [2].

9.2 Substances Prohibited at All Times

9.2.1 Non-approved Substances

Athletes are warned against the use of any substances that are not registered (or with expired/lost registration) for human therapeutic use. This includes also agents under evaluation in clinical trials.

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Table 9.1 List of adverse analytical findings and atypical findings reported by WADA accredited laboratories in 2012

AAS	2279	50.6 %
Stimulants	697	15.5 %
Cannabinoids	406	9.0 %
Glucocorticosteroids	365	8.1 %
Diuretics and other masking agents	322	7.2 %
Peptide hormones, growth factors, and related substances	181	4.0 %
Beta-2 agonists	131	2.9 %
Hormone and metabolic modulators	74	1.6 %
Narcotics	26	0.6 %
Beta-blockers	13	0.3 %
Alcohol	5	0.1 %
Enhancement of oxygen transfer	0	0.0 %
Chemical and physical manipulation	1	0.02 %
Total	4500	

9.2.2 Anabolic Agents

9.2.2.1 Anabolic-Androgenic Steroids (AAS)

AAS are probably the most common performance enhancers easily available all over the world. They are used by both elite and recreational athletes. There is no doubt that individuals keen on extreme disciplines may misuse AAS as well.

It is estimated that 2.4 % of Australian students report lifetime AAS use [3], while in Sweden between 10,000 and 100,000 subjects may be exposed to AAS every year [4]. Data from other countries and continents suggest that AAS users can be counted in millions [5–7]. The situation is emerging as a public health concern [8].

The most coveted by athletes effect of AAS is muscle hypertrophy. However, one cannot forget about side effects of these compounds. They are common and involve diverse body organs and systems [9–11]. One of the most prominent AAS effects in men is suppression of the hypothalamo-pituitary-gonadal (HPG) axis leading to decreased production of testosterone and spermatozoa. AAS abusers are at risk of acne, baldness, gynecomastia, cardiovascular diseases, lipid profile changes, liver tumors, and peliosis hepatis. Women may suffer from masculinization: decrease of the breasts size, changes in fat distribution and skin structure, hirsutism, losing scalp hair, deepening of the voice, and enlargement of the clitoris. Adolescents using ASS do not achieve the expected height due to premature epiphyseal closure.

AAS effects are not limited to the anabolic ones, but they exert also direct psychoactive actions. There is evidence that prone individuals may develop psychiatric dysfunction while using steroids. A number of studies link AAS abuse with increased risk of mania, anxiety, aggression, violence, or paranoia [12, 13].

Clinicians often observe AAS dependence in recreational or elite athletes. The long-term use of steroids, their higher doses, and greater dissatisfaction with body image are factors that increase such a risk. There are attempts to explain it by “myoactive” and psychoactive effects of steroid compounds [14]. Another important issue is depression or suicidal attempts following the withdrawal of AAS [15].

AAS may modulate neurotransmission in concert with other drugs of abuse. AAS are, e.g., used concomitantly with opioids. It is interesting that animal models show that AAS overdose induces changes similar to those observed after opioids [12]. Testosterone acts as a partial opioid agonist. AAS increase beta-endorphin levels in the ventral tegmental area and the thalamus. Nandrolone use is associated with decreased levels of kappa receptors in the nucleus accumbens and increased mu, delta, and kappa receptor binding in the hypothalamus, striatum, and midbrain periaqueductal gray [16, 17].

The classical pathways of AAS effects in the brain comprise androgen and estrogen receptors (alpha and beta) which are present in highest concentrations in basal telencephalon and diencephalon. The enzymes that play an important role here are 5α-reductase, aromatase, 3α-HSD, 3β-HSD, and 17β-HSD. AAS are thought to induce transcription and synthesis of new proteins [12].

Apart from genomic effects, AAS modulate kinase activity, ion channels, and G-protein second messenger systems. Some of these actions are much quicker than those induced through transcription factors [12].

Aggression is indicated as one of the most prominent behavioral traits in AAS abusers. It is observed even after discontinuation of AAS use. Animal studies prove that it can be attenuated by application of, e.g., selective serotonin reuptake inhibitors [18]. AAS reduce the expression of serotonin receptors in the anterior hypothalamus (1A), globus pallidus (1B), or hippocampus [19, 20]. Anabolic-androgenic steroids decrease serotonin concentration in basal forebrain and dorsal striatum [21] but increase in the cerebral cortex [22]. For example, methyltestosterone injections associate with rise in energy, sexual arousal, and shorter sleep. It is probably caused by elevation of serotonin within the cerebral cortex what was monitored by an increase of 5-hydroxyindoleacetic acid in the cerebrospinal fluid [23].

AAS are also likely to modify the mesolimbic dopamine system by stimulation of dopamine release and synthesis [22]. It has been shown in human volunteers that nandrolone injections increase the serum levels of dopamine metabolite – homovanilic acid [24].

Another central neurotransmission system that is involved in AAS actions is GABA system. Androgen derivatives diminish concentration of GABA receptors and thus reduce fear in animals [25]. It stands in line with observations of, e.g., male users of AAS.

9.2.2.2 Other Anabolic Agents

Clenbuterol is a beta-2 agonist used as a bronchodilator in asthma. It seems that dopers combine testosterone with clenbuterol more often than with GH, levothyroxine, EPO, or insulin [26]. Animal studies showed that clenbuterol increases muscle mass and decreases fat deposits. Catabolism is reduced up to 18 % what leads to a raise of the total protein content by 6 %.

Due to the use of clenbuterol in fattened animals (the procedure forbidden in EU and the USA), there is a risk of positive anti-doping testing after consumption of contaminated meat.

9.2.3 Peptide Hormones, Growth Factors, and Related Substances

9.2.3.1 EPO

Erythropoietin (EPO) is responsible for the oxygen-carrying capacity of the blood. When it is used in therapeutic doses, it may increase red blood cells and hemoglobin by 6–11 % and lead to raises in VO_{2max}. Sportsmen use EPO to increase aerobic power and endurance. The substance is applied as subcutaneous, intravenous, or intraperitoneal injections.

Compared with the first-generation recombinant human EPO, the second-generation products (e.g., darbepoetin) have extended half-life. Continuous erythropoiesis receptor activators (CERAs) are called the third-generation agents. The second- and third-generation EPO can be applied less frequently as their half-life reaches 140 h. A disadvantage of the newer forms of EPO – from the point of view of a doper – is longer period in which they can be detected. Cheating athletes may undertake training at higher altitudes or use altitude tents to mask EPO doping. The latter forms of performance enhancement are not forbidden. Thus increases of hematocrit could be attributed to the latter “procedures” rather than to doping with EPO.

Another problem of the recent years is availability of products biosimilar to EPO. Their structures and properties are different to the medically approved form, and they might not be detected by standard anti-doping tests [27].

Side effects of EPO comprise arterial hypertension, increased risk of arterial thrombosis, and venous thromboembolism but also flu-like symptoms (fever, arthralgias, muscle pains, conjunctivitis), skin allergic reactions, seizures, changes of serum potassium, urea, and phosphorus concentrations. EPO doping poses a special risk for dehydrated athletes, e.g., triathlonist or ultramarathon runners (a rise in the hematocrit can be augmented and reach even 80 %). One cannot exclude mitogenic effects of EPO when used in supraphysiological doses.

The first suspected cases of EPO doping were several cyclists who died suddenly in the late

1980s. The first documented darbapoietin dopers were four medalists of Salt Lake City 2002 Winter Olympics. The winner of the 2004 Hawaii Ironman Triathlon (Triathlon World Championship) Nina Kraft was stripped of the title by World Triathlon Corporation being found positive for EPO.

9.2.3.2 Gonadotropins

hCG stimulates synthesis of testosterone in the testes. It is not very popular, and it is used by male athletes only. The side effects are similar to those of AAS [28]. There is no scientific rationale for the use of gonadotrophins as “protection” for gonads during AAS doping.

9.2.3.3 GH/IGF-1

Growth hormone (GH), GH secretagogues, IGF-I, and its analogues began to gain their reputation in the sport world from the Los Angeles 1984 Summer Olympic Games. GH is desired for its anabolic and lipolytic properties. It is often applied together with AAS. In an anonymous American survey, 25 % of AAS buyers reported concomitant use of GH [29].

Our knowledge on GH effects is based mainly on studies in subjects with GH deficiency. In such cases, positive effects of GH administration on body composition and performance are well documented. GH is to increase VO_{2max} and exercise time. What stands in contrast – in patients with acromegaly (a model of GH excess) – one finds reduced aerobic fitness and reduced left ventricle ejection fraction.

GH decreases body fat, increases cardiac output, and enhances wound healing. Observed effects of GH in muscles comprise:

- ↑ diameter of muscle fibers
- ↑ muscle protein content
- ↑ number of muscle cell nuclei
- ↑ glucose uptake
- ↑ protein synthesis
- ↓ muscle protein degradation
- ↑ myoblast proliferation
- ↓ myoblast apoptosis

The scientifical evidence for effectiveness of GH as a performance-enhancing agent in healthy individuals is poor. Athletes administer 3–8 mg of GH/24 h on 3–4 days of every week (mean daily dose of GH is 1–2 mg). It is 2–3× higher than physiological pituitary secretion of GH [30]. In one double-blind, placebo-controlled study in the elderly testosterone combined with GH in a higher dose was less effective in changing muscle strength than testosterone with a lower dose of GH.

One must keep in mind that prolonged use of GH/IGF-1 in high doses is associated with a range of serious side effects. Among the most typical ones are edema, muscle and joint pain, arterial hypertension, headache, vertigo, tinnitus, nausea, vomitus, gynecomastia, insulin resistance, goiter, and mitogenesis (colon cancer).

Anti-doping laboratories developed techniques to detect GH/IGF-1 abuse; however, it still poses a challenge [31].

9.2.4 Beta-2 Agonists

Beta-2 agonists are the first-line therapeutics in bronchial asthma. The evidence seems to exclude their ergogenic effects (if inhaled). For example, there was no improvement in 5 km time-trial performance following the inhalation of up to 1600 μg of salbutamol in non-asthmatic athletes [32]. Nevertheless, it is intriguing that prevalence of asthma is several times higher in elite athletes (Olympic medalists) than in general population.

Dopers are supposed to use beta-2 agonists in doses exceeding recommended levels by several times. Agents such as salbutamol, salmeterol, and fenoterol applied in high doses increase glycogenolysis, lipolysis, and muscle contractility. They stimulate insulin and growth hormone secretion. Animal studies show that beta-2 agonists decrease degradation of proteins and stimulate muscle mass gain. Such effects have been not unequivocally confirmed in humans; however, it is suspected that beta-2 agonists may enhance muscle strength and endurance in mechanisms not elucidated yet. Typical signs of intoxication are headaches, vertigo, chest pain, dyspnoe, tremor, sweating, tachycardia, hypotonia, hyperglycemia, hypokalemia, and myocardial damage (leading to heart infarcts).

9.2.5 Hormone and Metabolic Modulators

The list includes aromatase inhibitors (e.g., anastrozole), selective estrogen receptor modulators (e.g., raloxifene), other anti-estrogenic substances (e.g., clomiphene), agents modifying myostatin function (e.g., myostatin inhibitors), and metabolic modulators (e.g., insulin).

Aromatase inhibitors (aminoglutethimide, anastrozole, letrozole, testolactone) inhibit the synthesis of estrogens from AAS or testosterone. They are registered for the treatment of breast cancer. They may stimulate LH secretion and further increase production of testosterone. Similar effects are observed during the application of clomiphene, which is used in ovulatory dysfunction in infertile women. Selective estrogen receptor modulators (SERMs) may behave as agonists or antagonists of the estrogen receptor (depending on the tissue). They oppose bone loss, and they are used to prevent osteoporosis in postmenopausal women.

Myostatin is a negative regulator of skeletal muscle mass. It is a member of transforming growth factor family. Animal and human observations indicate that mutations of the myostatin gene result in muscle hypertrophy. In the absence of myostatin, muscle fibers show hypertrophy, hyperplasia, changes of glucose, and fat metabolism. Myostatin inhibitors have a potential to be used by athletes to increase their muscle mass. Among such inhibitors one can find antibodies or proteins directed against myostatin. So far neither of these substances has been approved for the treatment of humans.

Insulin has potent anabolic properties. It acts synergistically with growth hormone and androgens. Insulin increases the uptake of glucose into adipose/muscle tissues and stimulates glycogenesis what improves postexercise recovery. Apart from the impact on glucose metabolism, insulin inhibits proteolysis and thus enables muscle mass gain. During the application of insulin, there are observed improvements of endurance. Tissue repair processes are facilitated as well. A dangerous side effect of insulin use is the risk of hypoglycemia. Athletes using insulin may experience hypoglycemia even long hours after its application. As a growing number of sportspersons use AAS, glucocorticosteroids, or GH, they may develop insulin resistance what in turn may require insulin therapy. There are some unanswered questions in regard to diagnosing and treating of diabetes in athletes (potential doping properties).

9.2.6 Diuretics and Other Masking Agents

Diuretics modify the body fluid balance through enhanced renal excretion of salt and water. Athletes use diuretics mainly to achieve rapid weight loss. It may be required for, e.g., meeting a weight category before competition. Diuretics are also applied to mask the presence of other illegal doping agents. They increase urine flow and thus decrease concentration of a specific substance in urine (dilution). They may also change urine acidity [33].

Recent WADA reports indicate that diuretics are present in more than 7 % of cases positive for doping.

9.3 Methods

9.3.1 Chemical and Physical Manipulation

Any attempts to change the status of samples taken during doping control are prohibited. There is also a warning against intravenous infusions and injections apart from these administered during legal, necessary medical procedures.

9.3.2 Manipulation of Blood and Blood Components

The administration of blood (autologous or heterologous) or red blood products and use of techniques to optimize oxygen delivery are prohibited. Blood manipulations increase the risk of life-threatening events such as cerebral and pulmonary embolism and stroke.

One of the first athletes who was known to use blood doping was Lasse Viren – 5000 and 10,000 m steeplechase gold medalist at the Munich Olympic Games in 1972. Nowadays the main procedure used by cheaters is autologous blood transfusion, as heterologous one is easy to detect and very risky.

“Operacion Puerto” led by Spanish authorities revealed systemic use of autologous blood transfusion by many athletes. Blood was withdrawn and stored refrigerated for several weeks before major competitions and then it was reinfused a few days before the event. Top sportsmen might use cryopreservation of blood which is a more expensive alternative of blood storage.

Another important problem is substances that modify expression of EPO or other genes. Some of them are comfortable to use (e.g., cobalt salt tablets that can be taken orally); however, this may be associated with serious health-hazards (cardiac and thyroid disturbances). There is, e.g., a potential to modify the expression of hypoxia-inducible genes by inhibiting hypoxia-inducible factor (HIF). One of the possible ways to achieve this goal is to inhibit HIF prolyl hydroxylase (enzyme that regulates HIF). It could lead to increased production of EPO [27].

Artificial ways of blood enhancement (e.g., hemoglobin-based blood substitutes or perfluorochemicals) are forbidden as well.

9.3.3 Gene Doping

Gene doping means the enhancement of performance by transfer or manipulation of genetic material. Genes may be derived from cells acquired from the organisms, which are modified out of the body and then transferred back into the organism, or the procedures that involve actions in vivo only (straight gene/nucleic acid transfer).

So far, the attempts to use gene therapy in treating specific diseases have not brought spectacular results. The greatest obstacle is unpredictable side effects of such manipulations which include fatal outcomes.

Genes that attract greatest attention in regard to sport performance are genes that encode erythropoietin (EPO), vascular endothelial growth factor (VEGF), peroxisome proliferator-activated receptors and co-activators, insulin-like growth factor 1(IGF-1), myostatin (MSTN), follistatin (FST), growth-hormone (GH), or GH-releasing hormone (GH-RH).

Genetic modifications are not easily detectable by anti-doping procedures, though there is a constant progress in this field. Researchers work on direct methods or combinations of indirect techniques to detect such an abuse in athletes [34]. Up till now no cases of gene doping in sports have been revealed.

9.4 Substances and Methods Prohibited In Competition

9.4.1 Stimulants

Drinking coffee and smoking cigarettes are cultivated in many parts of the world. They belong to the most common human addictions. There is evidence showing that caffeine and nicotine improve concentration, but effects can be expected also in other areas desired by extreme sport participants.

Caffeine ingestion may have positive influence on performance in both aerobic and anaerobic activities. There are observed increases of endurance and maximal cycling power. Caffeine positively impacts cognitive functions, motor skills, and the postexercise recovery time. Some role is attributed to mild analgesic properties of the substance.

Nicotine activates the sympathetic nervous system. It stimulates secretion of catecholamines and increases muscle blood flow and lipolysis. Athletes using nicotine revealed enhancements in learning, memory, attention, reaction time, and motor abilities. The time to exertion is lengthened, and similarly to caffeine sensibility to pain is reduced [35].

Caffeine was banned by WADA until 2003. Caffeine and nicotine are not included in the List of Prohibited Substances and Methods. Bupropion, phenylephrine, phenylpropanolamine, pipradol, and synephrine are not considered as banned substances either.

9.4.2 Narcotics

This group of psychoactive agents comprises diverse compounds. Among a broad range of actions, they may induce desirable analgesia. On the other hand, the use of, e.g., derivatives of morphine leads to frequent side effects: low blood pressure, dizziness, drowsiness, and constipation. Less frequently are noted: bradycardia, bronchospasm, rash, or blurred vision.

Authors of an anonymous survey of British recreational divers reported that 22 % of the respondents used illicit substances such as benzodiazepines, amphetamine, cocaine, ecstasy, LSD, heroin, or “magic mushrooms” [36].

The following are prohibited: buprenorphine, dextromoramide, diamorphine (heroin), fentanyl and its derivatives, hydromorphone, methadone, morphine, oxycodone, oxymorphone, pentazocine, and pethidine.

9.4.3 Cannabinoids

At present cannabis is an illegal substance in majority of the countries. Its use by athletes is forbidden in competition only. Cannabinoids are among the most common substances detected during anti-doping testing (after AAS).

Cannabis contains a range of chemical compounds including over 60 cannabinoids. Smoking of cannabis results in the formation of more than 2000 chemical agents. The psychoactive actions of the plant are attributed to tetrahydrocannabinol (THC) and to a much smaller extent – cannabinol. Other cannabinoids exert anxiolytic, antipsychotic, and alerting effects (e.g., cannabidiol).

Cannabis changes cognitive and behavioral functions. It affects perception and time reception, induces euphoria and relaxation, and enhances sensory experiences. Upon cannabis use, short-time memory, reaction time, and motor skills are impaired. Among the physiological effects are increased heart rate, alterations of blood pressure, bronchodilation, increased appetite, dry mouth/throat, analgesia, and sedation.

Athletes explain that cannabis eases stress and anxiety. It is to improve concentration and enhance creativity. It may reduce muscle tension and provide better sleep.

The side effects of cannabis comprise anxiety and panic reactions. Long-term users may develop chronic bronchitis, reproductive disturbances, impairments of attention/memory, and a dependence syndrome [37].

Cannabis is the most common drug, next to alcohol, in drivers involved in fatal accidents or stopped for impaired driving. It impairs piloting as well [38, 39].

The use of cannabis by athletes may influence technical skills and decision-making. It increases the risk of incidents and injuries.

9.4.4 Glucocorticosteroids

Glucocorticosteroids (GCSs) are used to treat various diseases of the skin, respiratory, alimentary, endocrine, and musculoskeletal systems. Athletes get familiar with this class of medications while suffering from musculotendinous inflammatory processes. Another common use is in the therapy of allergic rhinitis and bronchial asthma.

Anti-inflammatory properties of GCS can shorten the recovery period after contusions. It may be attractive in a whole range of sports.

On the other hand, the application of GCS is associated with the risk of serious side effects. Among the most characteristic are increased risk of infections (fungal ones if inhaled), acne, thin skin, bruising, delayed wound healing, gastritis, weight gain, myopathy, heart rate disturbances, increased blood pressure, diabetes mellitus, osteoporosis, glaucoma and cataracts, mood changes, aggression, and depression.

9.5 Substances Banned in Particular Sports

9.5.1 Alcohol

In many cultures, alcohol is an ingredient of everyday diet. Moderate alcohol consumption favorably influences the risk of cardiovascular disease. On the other hand, alcohol abuse is linked to cardiomyopathy, arrhythmias, stroke, arterial hypertension, liver disease (steatosis, hepatitis, cirrhosis), pancreatitis, cancer (mouth, esophagus, throat, larynx, liver, breast), and immune disturbances.

Alcohol has ergolytic effects and its chronic use induces myopathy. It decreases utilization of glucose and reduces skeletal muscle capillarity [35].

Alcohol impairs psychomotor performance and increases the risk of injury. It has detrimental effects on endurance, and it may negatively affect recovery period.

Alcohol is banned in competition in sports such as aeronautics, archery, automobile, karate, motorcycling, and power boating.

9.5.2 Beta-Blockers

Beta-blockers oppose actions of catecholamines exerted through beta-receptors. They decrease heart rate and lower blood pressure. Agents such as bisoprolol, metoprolol, atenolol, or propranolol are widely used in conditions such as cardiac arrhythmias, ischemic heart disease, heart failure, arterial hypertension, and hyperthyreosis.

In sports, beta-blockers are used for their anxiolytic effects. They can positively influence performance in activities in which the lack of hand tremor and steadiness are required (sport shooting, archery). Beta-blockers impair endurance. They decrease maximum exercise load, lipolysis, and muscle glycogenolysis [40].

Conclusion

It is a common knowledge that a significant percentage of physically active people use banned substances to enhance their performance. The temptation seems to be similar for individuals engaging in popular and extreme sports, professional and recreational athletes.

At the moment, there are reliable laboratory methods to detect doping with EPO, GH, homologous blood transfusion, AAS, stimulants, SARMs, and other substances. Nevertheless, in spite of a significant increase of the number of anti-doping tests (from 150,000 to 250,000 annually), the efforts of the anti-doping community do not bring the expected results. The ratio of positive cases remains low (less than 1 %) and nearly constant from 1985.

It is especially disappointing in the context of affairs such as BALCO's, Festina's, Floyd Landis's, or Lance Armstrong's (to count just a few). It is assumed that this situation is not caused by technical or scientific insufficiency but is due to human and organizational failure.

References

1. World Anti-Doping Agency (WADA). CODE Signatories. https://www.wada-ama.org/en/what-we-do/the-code/code-signatories. Accessed 10 Aug 2014.
2. World Anti-Doping Agency (WADA). 2012 Anti-Doping Testing Figures Report. http://www.nada.at/files/doc/Statistiken/WADA-2012-Anti-Doping-Testing-Figures-Report-EN.pdf. Accessed 10 Aug 2014.
3. Dunn M, White V. The epidemiology of anabolic-androgenic steroid use among Australian secondary school students. J Sci Med Sport. 2011;14(1):10–4.
4. Lood Y, Eklund A, Garle M, Ahlner J. Anabolic androgenic steroids in police cases in Sweden 1999–2009. Forensic Sci Int. 2012;219(1–3):199–204.
5. Galduroz JC, Noto AR, Nappo SA, Carlini EA. Household survey on drug abuse in Brazil: study involving the 107 major cities of the country–2001. Addict Behav. 2005;30(3):545–56.
6. Rachon D, Pokrywka L, Suchecka-Rachon K. Prevalence and risk factors of anabolic-androgenic steroids (AAS) abuse among adolescents and young adults in Poland. Soz Praventivmed. 2006;51(6):392–8.
7. Harmer PA. Anabolic-androgenic steroid use among young male and female athletes: is the game to blame? Br J Sports Med. 2010;44(1):26–31.
8. Kanayama G, Hudson JI, Pope Jr HG. Long-term psychiatric and medical consequences of anabolic-androgenic steroid abuse: a looming public health concern? Drug Alcohol Depend. 2008;98(1-2):1–12.
9. Angell P, Chester N, Green D, Somauroo J, Whyte G, George K. Anabolic steroids and cardiovascular risk. Sports Med. 2012;42(2):119–34.
10. Turillazzi E, Perilli G, Di Paolo M, Neri M, Riezzo I, Fineschi V. Side effects of AAS abuse: an overview. Mini Rev Med Chem. 2011;11(5):374–89.
11. Quaglio G, Fornasiero A, Mezzelani P, Moreschini S, Lugoboni F, Lechi A. Anabolic steroids: dependence and complications of chronic use. Intern Emerg Med. 2009;4(4):289–96.
12. Wood RI. Anabolic-androgenic steroid dependence? Insights from animals and humans. Front Neuroendocrinol. 2008;29(4):490–506.

13. Pope Jr HG, Katz DL. Affective and psychotic symptoms associated with anabolic steroid use. Am J Psychiatry. 1988;145(4):487–90.
14. Brower KJ. Anabolic steroid abuse and dependence in clinical practice. Phys Sportsmed. 2009;37(4):131–40.
15. Thiblin I, Runeson B, Rajs J. Anabolic androgenic steroids and suicide. Ann Clin Psychiatry. 1999;11(4):223–31.
16. Johansson P, Hallberg M, Kindlundh A, Nyberg F. The effect on opioid peptides in the rat brain, after chronic treatment with the anabolic androgenic steroid, nandrolone decanoate. Brain Res Bull. 2000;51(5):413–8.
17. Johansson P, Lindqvist A, Nyberg F, Fahlke C. Anabolic androgenic steroids affects alcohol intake, defensive behaviors and brain opioid peptides in the rat. Pharmacol Biochem Behav. 2000;67(2):271–9.
18. Grimes JM, Melloni Jr RH. Serotonin modulates offensive attack in adolescent anabolic steroid-treated hamsters. Pharmacol Biochem Behav. 2002;73(3):713–21.
19. Ricci LA, Rasakham K, Grimes JM, Melloni Jr RH. Serotonin-1A receptor activity and expression modulate adolescent anabolic/androgenic steroid-induced aggression in hamsters. Pharmacol Biochem Behav. 2006;85(1):1–11.
20. Kindlundh AM, Lindblom J, Bergstrom L, Nyberg F. The anabolic-androgenic steroid nandrolone induces alterations in the density of serotonergic 5HT1B and 5HT2 receptors in the male rat brain. Neuroscience. 2003;119(1):113–20.
21. Lindqvist AS, Johansson-Steensland P, Nyberg F, Fahlke C. Anabolic androgenic steroid affects competitive behaviour, behavioural response to ethanol and brain serotonin levels. Behav Brain Res. 2002;133(1):21–9.
22. Kurling S, Kankaanpaa A, Ellermaa S, Karila T, Seppala T. The effect of sub-chronic nandrolone decanoate treatment on dopaminergic and serotonergic neuronal systems in the brains of rats. Brain Res. 2005;1044(1):67–75.
23. Daly RC, Su TP, Schmidt PJ, Pickar D, Murphy DL, Rubinow DR. Cerebrospinal fluid and behavioral changes after methyltestosterone administration: preliminary findings. Arch Gen Psychiatry. 2001;58(2):172–7.
24. Hannan Jr CJ, Friedl KE, Zold A, Kettler TM, Plymate SR. Psychological and serum homovanillic acid changes in men administered androgenic steroids. Psychoneuroendocrinology. 1991;16(4):335–43.
25. Clark AS, Costine BA, Jones BL, Kelton-Rehkopf MC, Meerts SH, Nutbrown-Greene LL, et al. Sex- and age-specific effects of anabolic androgenic steroids on reproductive behaviors and on GABAergic transmission in neuroendocrine control regions. Brain Res. 2006;1126(1):122–38.
26. Cordaro FG, Lombardo S, Cosentino M. Selling androgenic anabolic steroids by the pound: identification and analysis of popular websites on the Internet. Scand J Med Sci Sports. 2011;21(6):247–59.
27. Morkeberg J. Blood manipulation: current challenges from an anti-doping perspective. Hematology Am Soc Hematol Educ Program. 2013;627–31.
28. Barroso O, Mazzoni I, Rabin O. Hormone abuse in sports: the antidoping perspective. Asian J Androl. 2008;10(3):391–402.
29. Parkinson AB, Evans NA. Anabolic androgenic steroids: a survey of 500 users. Med Sci Sports Exerc. 2006;38(4):644–51.
30. Nelson AE, Ho KK. Abuse of growth hormone by athletes. Nat Clin Pract Endocrinol Metab. 2007;3(3):198–9.
31. Baumann GP. Growth hormone doping in sports: a critical review of use and detection strategies. Endocr Rev. 2012;33(2):155–86.
32. Dickinson J, Hu J, Chester N, Loosemore M, Whyte G. Acute impact of inhaled short acting b2-agonists on 5 km running performance. J Sports Sci Med. 2014;13(2):271–9.
33. Cadwallader AB, de la Torre X, Tieri A, Botre F. The abuse of diuretics as performance-enhancing drugs and masking agents in sport doping: pharmacology, toxicology and analysis. Br J Pharmacol. 2010;161(1):1–16.
34. Baoutina A. Performance enhancement by gene doping. In: Bouchard C, Hoffman EP, editors. Genetic and molecular aspects of sport performance. Chichester: Wiley-Blackwell; 2011. p. 373–82.
35. Pesta DH, Angadi SS, Burtscher M, Roberts CK. The effects of caffeine, nicotine, ethanol, and tetrahydrocannabinol on exercise performance. Nutr Metab (Lond). 2013;10(1):71.
36. Dowse MS, Shaw S, Cridge C, Smerdon G. The use of drugs by UK recreational divers: illicit drugs. Diving Hyperb Med. 2011;41(1):9–15.
37. Hall W, Solowij N. Adverse effects of cannabis. Lancet. 1998;352(9140):1611–6.
38. Huestis MA, Mazzoni I, Rabin O. Cannabis in sport: anti-doping perspective. Sports Med. 2011;41(11):949–66.
39. Ashton CH. Pharmacology and effects of cannabis: a brief review. Br J Psychiatry. 2001;178:101–6.
40. Davis E, Loiacono R, Summers RJ. The rush to adrenaline: drugs in sport acting on the beta-adrenergic system. Br J Pharmacol. 2008;154(3):584–97.

Part II

Injuries and Illnesses in the Most Popular Extreme Sports

10 Rock and Ice-Climbing Medicine

Volker Schöffl

10.1 Introduction

Rock and ice climbing diversified from mountaineering with various forms of activities, such as sport climbing or deep water soloing. The overall climbing performance is depending on psychological factors (e.g. finger strength, BMI), mental capability and technique. Climbing sports can be performed from a young age up to a very advanced age. The overall injury rate is low, with most injuries being of minor severity. Nevertheless the risk of a fatal injury is always present. Both injury rate and fatality rate vary from the different subdisciplines performed and are the lowest for indoor climbing, bouldering or sport climbing. They are naturally higher for alpine climbing or free solo climbing. External factors as objective danger through, e.g. wind chill or rockfall add to the risk. Most injuries and overstrain are on the upper extremity, mostly at the hands and fingers. Climbing is known to be beneficial for both the musculoskeletal system and the mind. It is used in physical therapy, behavioural training and similar social integrational activities.

10.2 Definition

Rock climbing originated from mountaineering but diversified within the early 1980s. As originally the main goal was just to reach the top, climbers in the Yosemite Valley in the United States and in the Elbsandstein in Eastern Germany started a different approach and tried to climb the hardest possible way without using technical aid [1]. The idea of "free climbing" was born. Its popularity spread globally and diversified to include new categories like ice climbing, bouldering, speed, pure aid climbing and deep water soloing. Simultaneously in mountaineering the routes to reach the summit became more and more difficult and extreme. Nowadays outdoor and indoor competition climbing are also very popular [2], but as this book focuses on extreme sports we will only focus onto outdoor climbing activities.

With any sporting participation, there will be some risk of injury that must be weighed against the benefits of this exercise. To date no known study has demonstrated that rock and ice climbing in general are high-risk sports [3, 4], a commonly held perception. Nevertheless extreme

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alpine climbing or solo climbing certainly qualifies.

Epidemiological analysis of sport-specific injuries helps inform preventive measures that can target the incidence and reduce their severity. Extensive studies on injuries in general rock climbing, indoor climbing and competition climbing exist, including analysis of the injury risk per 1000 h [5–28]. Most injuries in rock climbing occur on the upper limbs, notably the fingers, and are generally a result of overstraining rather than acute injuries [29].

10.2.1 Various Types of Climbing and Main Techniques

Rock climbing is a multidisciplined sport. Depending on the subdiscipline, the climber's experience and skills, grade of route's difficulty, equipment, climbing surface, remoteness of location, altitude and weather will implicate different levels of risk and difficulty. In addition to these variables, many climbers regularly participate in more than one climbing subdiscipline.

10.2.1.1 Sport Climbing

Sport climbing or free climbing requires gymnastic-like strength, flexibility, finger strength and strength endurance when climbing each unique and graded route. The climbing is slightly prescriptive as the climber ascends towards mostly permanently fixed anchors, such as bolts, to clip their rope into for protection. Falls are frequent, trained for and are mostly harmless. Physical hazards (rockfall, weather changes, etc.) are small, and the neglect of wearing a climbing helmet is widely accepted [3, 4, 30] (Fig. 10.1).

10.2.1.2 Bouldering

Bouldering consists of ropeless climbing involving a short sequence of powerful and technical moves to complete the graded route on large rocks. Bouldering can be done without a partner and with minimal equipment – climbing shoes and crash pad. Falling onto one's feet or body is a normal part of bouldering, whether a route is completed or not [4, 30] (Fig. 10.2).

10.2.1.3 Deep Water Soloing

Deep water soloing (DWS), also known as "psicobloc", is solo rock climbing, practised on sea cliffs at high tide, that relies solely upon the presence of water at the base of a climb to protect against injury from falls. These routes can be up to 20+ metres high, and lately some of the hardest climbs in the world have been established in that styles (e.g. Chris Sharma, Es Pontàs, Spain) (Fig. 10.3).

Fig. 10.1 Sport climbing

Fig. 10.2 Bouldering

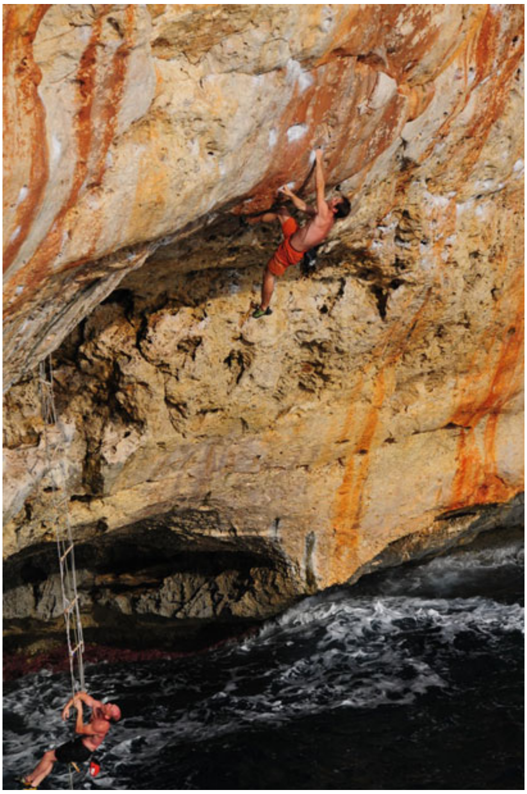

Fig. 10.3 Deep water soloing

10.2.1.4 Traditional Climbing

Traditional (alpine) climbing (or *trad climbing*) emphasises the skills necessary for establishing routes in an exploratory fashion outdoors. The lead climber typically ascends a section of rock while placing removable protective devices where possible along the climb. Falls can therefore be longer than those experienced when sport climbing. Unreliable fixed pitons may occasionally be found on older established routes. As physical hazards are likely, the use of a helmet is considered mandatory. Above around 2500 m, psychological altitude-induced adaptations must also be factored into the climbs [4, 30] (Fig. 10.4).

Fig. 10.4 Alpine climbing

10.2.1.5 Indoor Climbing and Competition Climbing

Indoor climbing and competition climbing are performed on artificial structures that try to mimic climbing outdoors but in a more controlled environment. As physical hazards are almost totally eliminated, such climbing became an

Fig. 10.5 Competition climbing

Fig. 10.6 Ice climbing

extracurricular sport in many countries. National and international competitions are held on such walls and involve three major disciplines – lead climbing (i.e. sport climbing), speed and bouldering. Indoor bouldering is performed above thick foam mat flooring [4, 30] (Fig. 10.5).

10.2.1.6 Ice Climbing

Ice climbing normally refers to roped and protected climbing of features such as icefalls, frozen waterfalls and cliffs and rock slabs covered with ice refrozen from flows of water. Equipment includes ice axes for hands and crampons for feet. Physical hazards like avalanches, rock and icefalls are present [4, 30, 31] (Fig. 10.6).

10.2.1.7 Free Solo Climbing

In contrast to the public perception, real free solo ascents are rare and don't play a major role in the current climbing sports. Nevertheless if performed they usually get a high media attention, thus mimicking a higher prevalence. The injury and fatality risk is obviously high.

10.2.2 Main Psychological and Anthropometric Characteristics

Based on the fact that climbing is not a cyclic but a poly-structural sport, it is difficult to evaluate the performance-limiting factors, of which many are still not verified [32–36]. One important factor is the anthropometric profile of the athletes, which was subject of a few studies of general climbers and elite competitors in lead climbing (sport climbing) [32, 37–41]. In the scientific literature climbers are described as being relatively small in stature and having a very low percentage of body fat [32]. Unexpectedly, their hand grip strength measured via dynamometer does not differ from non-climbers, because of the nonspecific

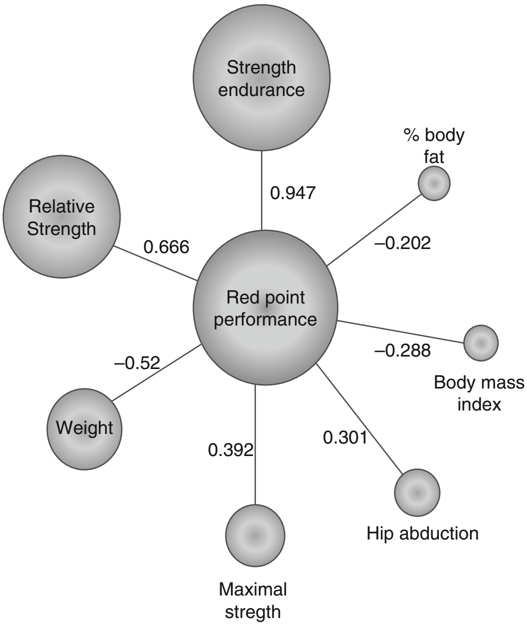

Fig. 10.7 Correlations between the red point achievements and some of the factors of performance, Michailov (2006) [43]

grip position in this test [36, 38–40]. Elite climbers are also stronger with the left hand (which is more often the nondominant hand) than recreational climbers and non-climbers [38]. The reason is probably connected to the fact that climbing develops strength and agility for both hands [32]. Many components have been proposed which correlate with the overall climbing performance [32, 33, 36]. However, some authors have proven the major importance of the specific strength endurance in sport climbing with strong correlation coefficients [42–44]. More recent studies support the fact that rock climbing requires harmoniously developed physical fitness, technical and tactical skills, as well as mental preparation [43] (Fig. 10.7).

10.2.3 Psychological and Behavioural Characteristics

The psychological and behavioural characteristics of any climbing subdiscipline are rarely studied, though they are a key performance variable that may additionally have an influence on injuries and fatalities sustained [46–48]. It is generally accepted that those rock climbers high in self-efficacy participate more frequently, take calculated additional risks and attempt harder climbs when they feel confident in their abilities, though this is rarely studied [4, 46].

10.3 Benefits from This Sport

Learning to climb has never been easier with the advent of indoor artificial climbing walls found in many cities [20]. In some schools it even forms part of the sport curriculum [1, 49]. Rock climbing participation is accessible at all ages, toddler to pensioner [1, 33, 49, 50], and is enjoyed by many over a lifetime. In a recent study we analysed our climbing patients between 2009 and 2012, where we saw climbers between a range of 11–77 years of age and 0.3–64 years of climbing [51]. Climbing sport is a lifelong activity with many health benefits, e.g. musculoskeletal training, equilibrium and mental training as well as minor injury risk [1]. Both genders can easily climb together and perform at an even level [1]. Its potential in rehabilitation and physiotherapy is widely used, as well as in behavioural training and social rehabilitation programmes [52–55].

10.4 Acute Injuries and Fatalities

Extensive studies on injuries in general rock climbing [1, 3, 4, 14, 15, 18, 21, 28, 56–65], indoor climbing [6, 18, 20, 24] and competition climbing [8, 49] exist, including analysis of the injury risk per 1000 h. Severe injuries during indoor or competition climbing are rare, but do happen [14, 15, 18–24, 27, 28, 49, 61, 64, 66–71]. Most injuries in rock climbing occur on the upper limbs, notably the fingers, and are generally a result of overstraining rather than acute injuries [19, 29, 69, 72–76]. Nevertheless in some studies more lower limb injuries are found [6, 11, 65]. Most injuries involve fractures, sprains and dislocations [3, 19, 28, 65, 76]. To date no known study has objectively demonstrated that ice and rock climbing are high-risk sports or that those climbing higher grades are more prone to experience severe injuries compared to those climbing lower grades. Nevertheless the media's lurid depiction of elite rock and ice climbers has helped to create a perception of climbing as being a hazardous and high-risk sport [77, 78]. For example, a 1999 *Time Magazine* cover featured a sport climber with the headline "Why we take risks" with a subtitle stating "From extreme sports to day trading thrill seeking is becoming more popular" [78].

To objectively analyse and compare injuries from different sports, a common scoring system for the grading of the injuries is essential. In general, when assessing whether a sport presents a high risk of injury or death, a distinction between overstrain (overuse) injuries and acute injuries or accidents should be made [4]. The reason is overstrain injuries are generally less severe and can generally be avoided with informed training, whereas an examination of the injury rate for acute sport-specific injuries, especially their severity, is crucial.

Most authors [5, 10, 11, 65, 76, 79] found that fractures, strains and sprains account for most injuries. Schöffl et al. [76] found the most common climbing injury the closed pulley rupture and the most common overuse injury the tenosynovitis of the finger flexor tendons. These pulley injuries are almost rock climbing-specific pathologies and matter of extensive research [60, 80–85]. Overall the majority of all injuries in the studies on outdoor and alpine climbing as well as bouldering studies were of minor severity (UIAA MedCom 1-2) [10, 15, 28, 60, 62–64, 70, 86].

Few studies examined ice-climbing injuries and overuse syndromes. In our study [31] we found that most of the acute injuries (61.3 %) occurred while lead climbing, 23.8 % while climbing second, and the rest was rare (6.3 % belaying, 3.8 % on return and 2.5 % on approach, other 2.5 %). Most of the acute injuries (73.4 %) happened in a waterfall, few in glacier ice walls (11.4 %) and on artificial ice walls (2.5 %). Climber fall-related acute injuries amounted for 10.5 %.

As there was an inconsistency in the use of scores for climbing studies and thus a lack of inter-study comparability, the Medical Commission of the UIAA (International Mountaineering and Climbing Federation) gave a consensus statement on injury and illness definition in mountain sports and proposed a new UIAA MedCom-Score88, which showed its value already in recent studies by Neuhof et al. [79] and Schöffl et al. [6]. The UIAA MedCom Score uses the OSICS 10 [88–90] tables for injury distribution and a new classification (Table 10.1). In addition a fatality risk classification and guidelines to evaluate a time-related injury risk are given [87].

Table 10.1 UIAA MedCom Score 2011 [87]. Injury and Illness Severity Classification (IIC) – UIAA MedCom Score

Score	Description
0	No injury or illness
1	Mild injury or illness, no medical intervention necessary, self-therapy (e.g. bruises, contusions, strains)
2	Moderate-severe injury or illness, not life threatening, prolonged conservative or minor surgery, outpatient therapy, doctor attendance within a short timeframe (days), injury-related work absence, heals without permanent damage (e.g. undisplaced fractures, tendon ruptures, pulley ruptures, dislocations, meniscal tear, minor frostbite)
3	Major injury or illness, not life threatening, hospitalisation, surgical intervention necessary, immediate doctor attendance necessary, injury-related work absence, heals with or without permanent damage (e.g. dislocated joint, fractures, vertebral fractures, cerebral injuries, frostbite with amputations)
4	Acute mortal danger, polytrauma, immediate prehospital doctor or experienced trauma paramedic attendance if possible, acute surgical intervention, outcome: alive with permanent damage
5	Acute mortal danger, polytrauma, immediate prehospital doctor or experienced trauma paramedic attendance if possible, acute surgical intervention, outcome: death
6	Immediate death

10.4.1 Fatalities

While some forms of rock climbing, such as solo climbing or alpine traditional climbing and clean climbing, show a larger injury risk, indoor and bolted sport climbing proved to be relatively safe [3, 4, 10, 12, 13, 18, 20, 65]. Nevertheless there is still a risk of a fatal injury. Few studies give exact data on a fatality rate, as many are conducted retrospectively. Statistics of the German Alpine Association reported seven deaths in the years 2006 and 2007 [91]. These statistics do not differentiate between traditional, ice and sport climbing. A retrospectively conducted study on mountaineering overall calculated an incidence of 0.13 fatalities per 1000 h [63]. For alpine climbing (traditional climbing), a death rate (fatality rate) was documented by Bowie [28] – 13 from 220 injured climbers died – a case fatality rate of 6 %. As most of analyses done in these climbing injury studies were conducted retrospectively through questionnaires, the fatality rate is frequently biased. The "older" studies (20 years ago) [28, 63, 64] reported the most severe injuries and the highest fatality rates, while recently a prospectively conducted study on bouldering [12] reported no fatalities.

The general death numbers in ice climbing can be analysed through the injury and fatality reports of the various Alpine clubs [31]. The Canadian [92] and the American Alpine Club [93] have statistically recorded and analysed all mountain accidents since 1951. In the USA, up to the year 2005, there were 6111 accidents with a total of 1373 (12 %) fatalities [93]. Two hundred fifty-four (4 %) of the accidents happened in ice, though no further evaluation of the ice-climbing injuries was given. Nevertheless if 4 % of all injuries are to be accounted to ice climbing, also 4 % of the deaths can be assumed to be related to ice climbing. This would calculate to 55 fatal ice-climbing injuries in 54 years, in average one ice-climbing fatality per year within the USA. The numbers for Canada are similar [92]. Over 30 years, 92 mountaineers were injured while ice climbing, 30 fatally. Overall the major ice-climbing countries, Switzerland and Canada, report about one death per year [92, 94]; nevertheless these numbers were rising in recent winters [31]. This is probably due to the fact that ice climbing itself became much more popular. For further understanding the UIAA MedCom also published a fatality risk classification [87] (Table 10.2).

Table 10.2 Fatality risk classification (FRC) (UIAA MedCom [87])

Class	Description
I	Fatalities are technically possible, but very rare. No objective danger, e.g. indoor climbing
II	Few objective dangers, fatalities rare, falls are not very dangerous, risk is mostly calculable – e.g. sport climbing, low elevation and technically easy peaks
III	High objective danger, risk is difficult to calculate, falls lead frequently to injuries, fatalities more frequent – e.g. traditional climbing, high Himalayan (7000–8000 m) or difficult peaks
IV	Extremely dangerous, falls have a high fatality rate, totally unjustified to normal mortals

10.5 Overstrain Injuries

Chronic overuse injuries occur most often on the upper extremities at the elbow and the fingers [15, 76, 79]. As hand and finger injuries are the most common injuries [1, 29, 60, 95], many studies focus on these anatomical regions [16, 29, 57–60, 69, 76, 95–99]. Schöffl et al. [51, 76] found over 10 years the most common climbing injury being the closed pulley rupture and the most common overuse injury the tenosynovitis of the finger flexor tendons. These pulley injuries are almost rock climbing-specific pathologies and matter of extensive research [60, 80–85]. Other finger injuries which are climbing specific are the "lumbrical shift syndrome" [100], "extensor hood syndrome" [101], "epiphyseal fractures" [75], "FLIP-syndrome" [102], "finger amputations – rope tangling injuries" [57], M. Dupuytren in young age [103] and osteoarthritis of the fingers [58, 104, 105]. In recent publications back problems ("climbers back" [106]) and shoulder pathologies (SLAP and biceps tendon tears [56, 107, 108]) as well as feet deformations were evolving [5, 109–111].

In ice climbing overstrain injuries are rare and hard to distinguish from other climbing training in its origin, as few climbers only practise ice climbing [31].

10.6 Diagnosis and Therapy of the Most Important Conditions

10.6.1 Pulley Injuries

Injuries to the finger flexor pulley system are the most common finger injuries in rock climbers [60]. The pulley system of the second to fifth

Table 10.3 Therapy guidelines for annular pulley injuries [60]

	Grade I	Grade II	Grade III	Grade IV
Injury	Pulley strain	Complete rupture of A4 or partly rupture of A2 or A3	Complete rupture of A2 or A3	Multiple ruptures, as A2/A3, A2/A3/A4 or single rupture (A2 or A3) combined with mm. lumbricalis or ligamental trauma
Therapy	Conservative	Conservative	Conservative	Surgical repair
Immobilisation	None	10 days	10–14 days	Postoperative 14 days
Functional therapy	2–4 weeks	2–4 weeks	4 weeks	4 weeks
Pulley protection	Tape	Tape	Thermoplastic or soft cast ring	Thermoplastic or soft cast ring
Easy sport-specific activities	After 4 weeks	After 4 weeks	After 6–8 weeks	4 months
Full sport-specific activities	6 weeks	6–8 weeks	3 months	6 months
Taping through climbing	3 months	3 months	6 months	>12 months

finger consists of five annular (A1-5) and three cross (C1-3) ligaments (pulleys). Caused mainly through the crimping position, the A2, A3 or A4 pulleys, which are considered the most important ones, can either be strained or ruptured. The most frequently injured pulley is the A2 pulley.

Mostly the climber reports of an acute onset of pain while crimping on a small edge [30]. Sometimes a loud "snapping" sound can be heard. The climber complains about palmar-sided pain at the level of the injured pulley, pressure tenderness, swelling and rarely haematoma. The pain can extend into the palm or the forearm. After clinical suspicion and exclusion of a fracture via radiograph, ultrasound examination leads to its detection. If multiple pulleys are ruptured, a clinical "bowstring" becomes visible. With the ultrasound an enhanced distance of the flexor tendons to the phalanx (tp) can be observed. If the ultrasound fails to give an exact diagnosis, an MRI should be performed. Based on a grading system and an algorithm proposed by Schöffl et al. [60], single ruptures receive a conservative and multiple ruptures a surgical therapy. Biomechanical analyses and strength measurements after conservative pulley ruptures of single pulley injuries proved no strength deficit of the injured finger, and the climbers gained their original climbing level back after 1 year. The outcome after surgical repair of multiple pulley injuries is also good, with mostly a full regain of climbing ability. Nevertheless often a minor restricted range of motion is persisting [112]. After pulley injury a protective taping with the biomechanical developed H-tape is recommended [30, 113] (Table 10.3, Fig. 10.8).

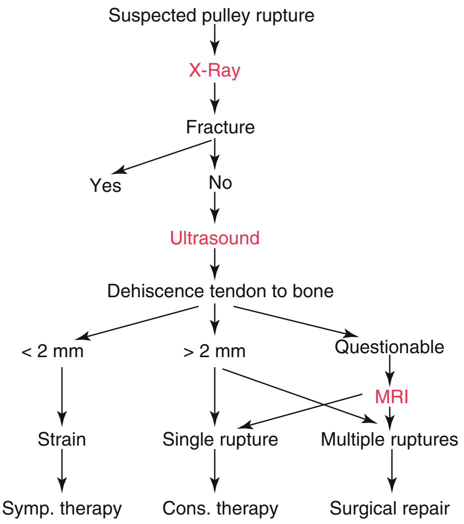

Fig. 10.8 Diagnostic-therapeutic algorithm in suspected pulley injury [60]

10.6.2 Tenosynovitis

Tenosynovitis is the most important differential diagnosis to the pulley injury and the most frequent overuse syndrome in climber's fingers

[1, 30, 51]. An inflammatory response occurs after repetitive stress, and its onset can be acute, after one exceptional hard training or climbing day, or slow over days. The climber has pain and minor swelling along the palmar surface of the digit, just around the same area as in a pulley injury [51]. The pain can extend into the palm or the forearm. The diagnosis can be proven through ultrasound, which detects a "halo" phenomena around the tendon [29, 51, 76]. This increased gathering of liquid around the tendon becomes best visible in a transversal plane. As climbers tend to have increased liquid in their flexor tendon sheets after high stress on various ranges, no clear information can be given about the normal range [51]. It is best to compare the ultrasound finding of the injured finger to the same one of the contralateral side. The therapy consists of anti-inflammatory medication, resting on a splint for several days, externals, brush massages, ice therapy and in a persisting condition local cortisone injection. Sometimes these injections are not avoidable as the chronic tenosynovitis can be stubborn [1, 51].

10.6.3 Fractures, Epiphyseal Fractures

They are mostly caused by direct trauma as rockfall or hiding the rock, while fall fractures occur in all varieties [1, 51]. Another injury mechanism is a jammed hand or finger in a crack or pocket and through non-axial forces or bending the finger an indirect trauma. Those fractures need to be treated according to trauma/orthopaedic surgical standards. Note that some minor fractures can present with the clinical symptoms of a pulley rupture; thus in suspicion of a pulley rupture an x-ray to exclude a fracture should be performed [1, 51]. Alarming is the rising number of epiphysiolyses and epiphyseal fractures of young climbers with no trauma [29, 51, 75, 114, 115]. Thus they need to be considered as fatigue fractures. The radiographs mostly show Salter-Harris III fractures of the dorsal part of the epiphysis of the PIP joint, which can be directly linked to using the crimp position. All patients reported about a slow onset of pain, and no real trauma was involved. They complained about pain at the interphalangeal joint in combination with swelling. If a standard radiograph shows no pathologic finding, an additional MRI is mandatory [29, 51, 75, 114, 115]. Those injuries need to be treated strictly; otherwise irreversible damage will be the result. In non-dislocated fractures and epiphysiolysis, conservative therapy with cast, splinting and stress reduction needs to be performed. If a dislocation is found, a surgical retention must be performed.

10.7 Equipment and Prevention

10.7.1 Injury Prevention

Injury prevention can be done from both sides, the climbers and the climbers' body, the UIAA (International Mountaineering and Climbing Federation) and the respective countries' Alpine clubs. The following bullet points can be or were already largely improved [1, 51]:

- Crash pad and spotting in bouldering
- Mats in indoor climbing
- Closure of mat gaps
- Route setting outdoors
- UIAA Safety Label
- Belay technique
- Fall technique

In bouldering a "crash pad" and a spotter should be used [1, 51]. A "crash pad" is a foldable mat with a thickness of about 10–15 cm which is positioned underneath the climber. These mats are widely used and are together with spotting the reason that in bouldering not more injuries occur than in roped climbing [1, 51]. Also a partner serves as a spotter in bouldering, which means he helps to position the falling climber in an erect position and onto the mat. Without running into the discussion, if climbs should be bolted or climbed free with jamming devices, in bolted routes, a general common sense on where to place the bolts is important. The bolts should not be so far apart that a ground fall is possible and always at a point where they can be clipped by smaller climbers as well. The UIAA safety commission gives safety labels (seals) to safety-approved equipment and only such equipment should be used. They perform intensive research on injury mechanism and avoidance of technical failures, e.g. in belay devices. A good belay and fall technique must be trained, so that the belayer does not catch the fall too statically, leading to a high impact of the climber hitting the rock. The same applies for learning how to best fall and which position in the fall is the safest [1, 6, 51].

10.7.2 Equipment

At the beginning of climbing, classic heavy mountaineering boots were worn for climbing in alpine regions as well as in rock faces [1, 51]. Only in the early 1980s, the first real climbing shoe with a friction sole entered the market. A characteristic that all climbing shoes have in common is the fact that they will have to be worn very tight in order to get an optimal contact to the rock, which will often lead to health problems, such as callosity, toe nail infections or in a longer time perspective a hallux valgus deformity. The introduction of bolts was an important factor for the explosive development of the climbing grades achieved. Falls into the rope are common for sport climbers now [57]. The climbing harnesses have also changed essentially. While a combination of chest and sit harness has been used in traditional mountaineering, a pure sit harness is deployed in sport climbing [57, 86]. This will allow an injury-free falling with maximum free movement while climbing. Bolts, ropes, harnesses and other equipment used should have the UIAA safety commission's approval [1, 51]. Also ice-climbing equipment developed a long way from the tools used in classical mountaineering. Modern crampons with the prominent frontal spikes have become standard. Nowadays a single frontal spike and even heel spurs are state of the art [31]. Ice axes have witnessed a transformation of long-shafted ice axes into a short-shafted curved cross-bar that looks like an assault weapon [1, 51]. It is widely discussed and hotly debated in the ice-climbing community whether ice axes should be used with or without leashes [1, 31, 51]. Leashes, which do reduce the stress onto the forearms, can increase the risk of injuring oneself during a fall, as they attach the ice axes to the body. In parallel with the technological advancements in crampons and ice axes, Erich Friedli from Switzerland developed the first real ice screws [1, 51]. These ice screws have played a pivotal role in increasing the safety of the sport. These screws guarantee a comparable pull-out strength to bolts if placed in good ice and at the correct angle [31]. Again, all of the used equipment should be UIAA proven.

Conclusion

Rock and ice climbing are fascinating sports which can be performed from childhood to an old age. They guarantee a full body workout together with mental, psychic and body awareness training. The injury rates are low, and most injuries of minor severity. Nevertheless fatalities do occur and proper training, equipment and precautions are necessary to reduce these risks. Partner check and redundancy are sequences from climbing similar to aviation and play lately a role in medical processes as well [116]. In outdoor climbing environmental factors and objective dangers as weather conditions, snow, rock- and icefall, etc., increase the injury risks. Appropriate preventive measures can reduce these risks.

References

1. Hochholzer T, Schöffl V. One move too many. 2nd ed. Ebenhausen: Lochner Verlag; 2006.
2. Schöffl V, Schöffl I. Competition climbing. Sportortho Sporttrauma. 2012;28:22–8.
3. Schöffl V, Morrison A, Schöffl I, Küpper T. Epidemiology of injury in mountaineering, rock and ice climbing in medicine and sport science. In: Caine D, Heggie T, editors. Epidemiology of injury in adventure and extreme sports, vol. 58. Basel: Karger; 2012. p. 17–43.
4. Schöffl V, Morrison AB, Schwarz U, Schöffl I, Küpper T. Evaluation of injury and fatality risk in rock and ice climbing. Sport Med. 2010;40(8):657–79.
5. Schöffl V, Kupper T. Feet injuries in rock climbers. World J Orthop. 2013;4(4):218–28.
6. Schöffl VR, Hoffmann G, Kupper T. Acute injury risk and severity in indoor climbing-a prospective analysis of 515,337 indoor climbing wall visits in 5 years. Wilderness Environ Med. 2013;24(3):187–94.

7. Folkl AK. Characterizing the consequences of chronic climbing-related injury in sport climbers and boulderers. Wilderness Environ Med. 2013;24(2):153–8.
8. Schöffl V, Burtscher E, Coscia F. Injuries and medical incidences during the IFSC 2012 Climbing World Cup Series. Med Sport. 2013;17(4):168–70.
9. Merritt AL, Huang JI. Hand injuries in rock climbing. J Hand Surg [Am]. 2011;36(11):1859–61.
10. Nelson NG, McKenzie LB. Rock climbing injuries treated in emergency departments in the U.S., 1990-2007. Am J Prev Med. 2009;37(3):195–200.
11. Backe S, Ericson L, Janson S, Timpka T. Rock climbing injury rates and associated risk factors in a general climbing population. Scand J Med Sci Sports. 2009;19(6):850–6.
12. Josephsen G, Shinneman S, Tamayo-Sarver J, Josephsen K, Boulware D, Hunt M, Pham H. Injuries in bouldering: a prospective study. Wilderness Environ Med. 2007;18(4):271–80.
13. Jones G, Asghar A, Llewellyn DJ. The epidemiology of rock climbing injuries. Br J Sports Med. 2007;773–8.
14. Smith LO. Alpine climbing: injuries and illness. Phys Med Rehabil Clin N Am. 2006;17(3):633–44.
15. Gerdes EM, Hafner JW, Aldag JC. Injury patterns and safety practices of rock climbers. J Trauma. 2006;61(6):1517–25.
16. Kubiak EN, Klugman JA, Bosco JA. Hand injuries in rock climbers. Bull NYU Hosp Jt Dis. 2006;64(3-4):172–7.
17. Stam C. Climbing injuries in the Netherlands. Inj Control Saf Promot. 2003;10(4):251–2.
18. Wright DM, Royle TJ, Marshall T. Indoor rock climbing: who gets injured? Br J Sports Med. 2001;35(3):181–5.
19. Rohrbough JT, Mudge MK, Schilling RC. Overuse injuries in the elite rock climber. Med Sci Sports Exerc. 2000;32(8):1369–72.
20. Schöffl V, Winkelmann HP. Accident statistics at "indoor climbing walls". Unfallstatistik an "Indoor-Kletteranlagen". Sportverletz Sportschaden. 1999;13(1):14–6.
21. Paige TE, Fiore DC, Houston JD. Injury in traditional and sport rock climbing. Wilderness Environ Med. 1998;9(1):2–7.
22. Wyatt JP, McNaughton GW, Grant PT. A prospective study of rock climbing injuries. Br J Sports Med. 1996;30(2):148–50.
23. Haas JC, Meyers MC. Rock climbing injuries. Sports Med. 1995;20(3):199–205.
24. Limb D. Injuries on British climbing walls. Br J Sports Med. 1995;29(3):168–70.
25. Maitland M. Injuries associated with rock climbing. J Orthop Sports Phys Ther. 1992;16:68–75.
26. Maitland M. Injuries associated with rock climbing. J Orthop Sports Phys Ther. 1992;16(2):68–73.
27. Rane A, Leal C. Injuries in sport climbing. In: Dubas FJV, editor. A colour atlas of mountain medicine. London: Wolfe Publishing; 1991. p. 176–82.
28. Bowie WS, Hunt TK, Allen Jr HA. Rock-climbing injuries in Yosemite National Park. West J Med. 1988;149(2):172–7.
29. Schöffl VR, Schöffl I. Finger pain in rock climbers: reaching the right differential diagnosis and therapy. J Sports Med Phys Fitness. 2007;47(1):70–8.
30. Schöffl V. Rock and ice climbing. In: Mei Dan O, Carmont MR, editors. Adventure and extreme sports injuries. New York/Hambrug: Springer; 2013. p. 7–35.
31. Schöffl V, Schöffl I, Schwarz U, Hennig F, Küpper T. Injury-risk evaluation in water ice climbing. Med Sport. 2009;2(1-2):32–8.
32. Michailov M, Mladenov L, Schöffl V. Anthropometric and strength characteristics of world-class boulderers. Medicine Sportiva. 2009;13:231–8.
33. Morrison AB, Schöffl VR. Review of the physiological responses to rock climbing in young climbers. Br J Sports Med. 2007.
34. Sheel AW. Physiology of sport rock climbing. Br J Sports Med. 2004;38(3):355–9.
35. Michailov M. Evolvement and experimentation of a new interval method for strength endurance development. In: Moritz EF, Haake S, editors. The engineering of sport, vol. 2. 6th ed. New York: Springer Science and Business Media; 2006. p. 291–6.
36. Watts PB. Physiology of difficult rock climbing. Eur J Appl Physiol. 2004;91(4):361–72.
37. Grant S, Hasler T, Davies C, Aitchison TC, Wilson J, Whittaker A. A comparison of the anthropometric, strength, endurance and flexibility characteristics of female elite and recreational climbers and non-climbers. J Sports Sci. 2001;19(7):499–505.
38. Grant S, Hynes V, Whittaker A, Aitchison T. Anthropometric, strength, endurance and flexibility characteristics of elite and recreational climbers. J Sports Sci. 1996;14(4):301–9.
39. Mermier CM, Janot JM, Parker DL, Swan JG. Physiological and anthropometric determinants of sport climbing performance. Br J Sports Med. 2000;34(5):359–65; discussion 366.
40. Watts PB, Joubert LM, Lish AK, Mast JD, Wilkins B. Anthropometry of young competitive sport rock climbers. Br J Sports Med. 2003;37(5):420–4.
41. Watts PB, Martin DT, Durtschi S. Anthropometric profiles of elite male and female competitive sport rock climbers. J Sports Sci. 1993;11(2):113–7.
42. Binney DM, Cochrane T. Identification of selected attributes, which significantly predict competition climbing performance in competitive rock climbing. J Sports Sci. 1999;17(1):11–2.
43. Michailov M. Study of some of the major factors of performance in climbing. Sport Sci. 2006;2:11–20.
44. Schöffl V, Möckel F, Köstermeyer G, Roloff I, Küpper T. Development of a performance diagnosis of the anaerobic strength endurance of the forearm flexor muscles in sport climbing. Int J Sports Med. 2006;27:205–11.
45. Magiera A, Roczniok R, Maszczyk A, Czuba M, Kantyka J, Kurek P. The structure of performance of a sport rock climber. J Hum Kinet. 2013;36:107–17.

46. Llewellyn DJ, Sanchez X. Individual differences and risk taking in rock climbers. Psychol Sport Exerc. 2008;9:423–6.
47. Williams ES, Taggart P, Carruthers M. Rock climbing: observations on heart rate and plasma catecholamine concentrations and the influence of oxprenolol. Br J Sports Med. 1978;12(3):125–8.
48. Sanchez X, Boschker MS, Llewellyn DJ. Pre-performance psychological states and performance in an elite climbing competition. Scand J Med Sci Sports. 2010;20(2):356–63.
49. Schöffl V, Küpper T. Injuries at the 2005 World Championships in rock climbing. Wilderness Environ Med. 2006;17:187–90.
50. BMC The British Mountaineering Council. www.thebmc.co.uk. 05 Jan 2009.
51. Schöffl V, Popp D, Küpper T, Schöffl I. Injury trends in rock climbers: evaluation of a case series of 911 injuries between 2009 and 2012 Wild Env Med. 2015;26(1):62–7.
52. Schöffl V, Winkelmann HP. Traumatic and degenerative tendon lesions of the hand. Orthopade. 2010;39(12):1108–16.
53. Madorsky JG, Kiley DP. Wheelchair mountaineering. Arch Phys Med Rehabil. 1984;65(8):490–2.
54. McClung SB. A rock climbing program as therapy for the chronically mentally ill. Northern Arizona Univ Diss. 1984.
55. Bienia J. Rock climbing as a factor in therapeutic rehabilitation. Chir Narzadow Ruchu Ortop Pol. 1962;27:643–51.
56. Schöffl V, Harrer J, Kupper T. Biceps tendon ruptures in rock climbers. Clin J Sport Med. 2006;16(5):426–7.
57. Schöffl V, Küpper T. Rope tangling injuries–how should a climber fall? Wilderness Environ Med. 2008;19(2):146–9.
58. Schöffl VR, Hochholzer T, Imhoff AB, Schoffl I. Radiographic adaptations to the stress of high-level rock climbing in junior athletes: a 5-year longitudinal study of the German junior national team and a group of recreational climbers. Am J Sports Med. 2007;35(1):86–92.
59. Schöffl V, Hochholzer T, Imhoff A. Radiographic changes in the hands and fingers of young, high-level climbers. Am J Sports Med. 2004;32(7):1688–94.
60. Schöffl V, Hochholzer T, Winkelmann HP, Strecker W. Pulley injuries in rock climbers. Wilderness Environ Med. 2003;14(2):94–100.
61. Rooks MD. Rock climbing injuries. Sports Med. 1997;23(4):261–70.
62. Rooks MD, Johnston 3rd RB, Ensor CD, McIntosh B, James S. Injury patterns in recreational rock climbers. Am J Sports Med. 1995;23(6):683–5.
63. Schussmann LC, Lutz LJ, Shaw RR, Bohn CR. The epidemiology of mountaineering and rock climbing accidents. Wilderness Environ Med. 1990;1:235–48.
64. Addiss DG, Baker SP. Mountaineering and rock-climbing injuries in US national parks. Ann Emerg Med. 1989;18(9):975–9.
65. Neuhof A, Hennig FF, Schöffl I, Schöffl V. Injury risk evaluation in sport climbing. Int J Sports Med. 2011;32(10):794–800.
66. Bannister P, Foster P. Upper limb injuries associated with rock climbing. Br J Sports Med. 1986;20(2):55.
67. Jebson JL, Steyers CM. Hand injuries in rock climbing: reaching the right treatment. Phys Sportsmed. 1997;25(5):1–7.
68. Killian RB, Nishimoto GS, Page JC. Foot and ankle injuries related to rock climbing. The role of footwear. J Am Podiatr Med Assoc. 1998;88(8):365–74.
69. Largiader U, Oelz O. An analysis of overstrain injuries in rock climbing. Schweiz Z Sportmed. 1993;41(3):107–14.
70. Logan AJ, Makwana N, Mason G, Dias J. Acute hand and wrist injuries in experienced rock climbers. Br J Sports Med. 2004;38(5):545–8.
71. Schafer J, Gaulrapp H, Pforringer W. Acute and chronic overuse injuries in extreme sport-climbing. Sportverletz Sportschaden. 1998;12(1):21–5.
72. Pfeifer C, Messner K, Scherer R, Hochholzer T. Injury pattern and overuse stress syndrome in young sport climbers. Wien Klin Wochenschr. 2000;112(22):965–72.
73. Holtzhausen LM, Noakes TD. Elbow, forearm, wrist, and hand injuries among sport rock climbers. Clin J Sport Med. 1996;6(3):196–203.
74. Stelzle FD, Gaulrapp H, Pforringer W. Injuries and overuse syndromes due to rock climbing on artificial walls. Sportverletz Sportschaden. 2000;14(4):128–33.
75. Hochholzer T, Schöffl VR. Epiphyseal fractures of the finger middle joints in young sport climbers. Wilderness Environ Med. 2005;16(3):139–42.
76. Schöffl V, Hochholzer T, Winkelmann HP, Strecker W. [Differential diagnosis of finger pain in sport climbers] Differentialdiagnose von Fingerschmerzen bei Sportkletterern. D Z Sportmed. 2003;54:38–43.
77. Schöffl V, Schöffl I, Schwarz U, Hennig F, Küpper T. Injury-risk evaluation in water ice climbing. Med Sport. 2009;13(4):210–8. doi:10.2478/v10036-009-0032-3.
78. Greenfeld KT. Adventure: life on the edge time-magazine, Why we take risks. Time Magazine. 1999;6 (US edition).
79. Neuhof A, Hennig FF, Schöffl I, Schöffl V. Injury risk evaluation in sport climbing. Int J Sports Med. 2011;32(10):794–800.doi:10.1055/s-0031-1279723.
80. Roloff I, Schöffl VR, Vigouroux L, Quaine F. Biomechanical Model for the determination of the forces acting on the finger pulley system. J Biomech. 2006;39(5):915–23.
81. Moutet F, Forli A, Voulliaume D. Pulley rupture and reconstruction in rock climbers. Tech Hand Up Extrem Surg. 2004;8(3):149–55.
82. Gabl M, Reinhart C, Lutz M, Bodner G, Angermann P, Pechlaner S. The use of a graft from the second extensor compartment to reconstruct the A2 flexor pulley in the long finger. J Hand Surg (Br). 2000;25(1):98–101.

83. Schöffl I, Oppelt K, Jungert J, Schweizer A, Neuhuber W, Schöffl V. The influence of the crimp and slope grip position on the finger pulley system. J Biomech. 2009;42(13):2183–7. doi:10.1016/j.jbiomech.2009.04.049.
84. Schöffl I, Oppelt K, Jungert J, Schweizer A, Bayer T, Neuhuber W, Schöffl V. The influence of concentric and eccentric loading on the finger pulley system. J Biomech. 2009;42(13):2124–8. doi:10.1016/j.jbiomech.2009.05.033.
85. Schöffl V, Schöffl I. Isolated cruciate pulley ruptures in rock climbers. J Hand Surg (European). 2010;35:245–6.
86. Hohlrieder M, Lutz M, Schubert H, Eschertzhuber S, Mair P. Pattern of injury after rock-climbing falls is not determined by harness type. Wilderness Environ Med. 2007;18(1):30–5.
87. Schöffl V, Morrison AB, Hefti U, Schwarz U, Küpper T. The UIAA medical commission injury classification for mountaineering and climbing sports. In No.17, 10.05.2010 ed; Official Standards of the Union Internationale des Associations d'Alpinisme (UIAA). 2010:1–8.
88. Fuller CW, Ekstrand J, Junge A, Andersen TE, Bahr R, VDvorak J, Hägglund M, McCrory P, Meeuwisse WH. Consensus statement of injury definitions and data collection procedures in studies of football (soccer) injuries. Scand J Med Sci Sports. 2006;16:83–92.
89. Orchard J. Orchard sports injury classification system (OSICS). Sport Health. 1995;11:39–41.
90. Rae K, Orchard J. The orchard sports injury classification system (OSICS) version 10. Clin J Sport Med. 2007;17(3):201–4.
91. DAV Bergunfallstatistik 2006–2007. German Alpine Club. München; 2008.
92. Canadian-Alpine-Club. www.alpineclub-edm.org/accidents/type.asp?type=Ice+Climbing.
93. American-Alpine-Club. Accidents in North American mountaineering. Am Alpine Club. 2006;9(1):59.
94. Mosimann U. Notfälle beim Eisklettern. Bergundsteigen. 2006;4:70–3.
95. Schöffl V. [Hand Injuries in rock climbing] Handverletzungen beim Klettern. D Z Sportmed. 2008;59(4):85–90.
96. Carmeli E, Wertheim M. [Hand injuries in young and old wall climbers] Handverletzungen bei jugendlichen und erwachsenen Sportkletterern. D Z Sportmed. 2001;52(10):285–8.
97. Bollen SR. Upper limb injuries in elite rock climbers. J R Coll Surg Edinb. 1990;35(6):18–20.
98. Bollen SR. Injury to the A2 pulley in rock climbers. J Hand Surg (Br). 1990;15(2):268–70.
99. Bollen SR, Gunson CK. Hand injuries in competition climbers. Br J Sports Med. 1990;24(1):16–8.
100. Schweizer A. Lumbrical tears in rock climbers. J Hand Surg (Br). 2003;28(2):187–9.
101. Schöffl V, Hochholzer T, Schöffl I. Extensor hood syndrome–osteophytic irritation of digital extensor tendons in rock climbers. Wilderness Environ Med. 2011;21(3):253–6.
102. Schöffl I, Bayer T, Schöffl V. Fl.I.P. (Flap irritation phenomenon): Etiology of chronic tenosynovitis after finger pulley rupture. J Appl Biomech, 2011, Epub Jul 29.
103. Logan AJ, Mason G, Dias J, Makwana N. Can rock climbing lead to Dupuytren's disease? Br J Sports Med. 2005;39(9):639–44.
104. Hochholzer T, Schöffl V. [Osteoarthrosis in finger-joints of rockclimbers] Degenerative Veränderungen der Fingergelenke bei Sportkletterern. D Z Sportmed. 2009;60(6):145–9.
105. Sylvester AD, Christensen AM, Kramer PA. Factors influencing osteological changes in the hands and fingers of rock climbers. J Anat. 2006;209(5):597–609.
106. Förster R, Penka G, Bosl T, Schöffl VR. Climber's back–form and mobility of the thoracolumbar spine leading to postural adaptations in male high ability rock climbers. Int J Sports Med. 2009;30(1):53–9.
107. Schöffl V, Popp D, Dickschass J, Kupper T. Superior labral anterior-posterior lesions in rock climbers-primary double tenodesis? Clin J Sport Med. 2011;21:261–3.
108. Schöffl V, Schneider H, Kupper T. Coracoid impingement syndrome due to intensive rock climbing training. Wilderness Environ Med. 2011;22(2):126–9.
109. Morrison AB, Schöffl V. Climbing shoes – is pain insane? www.thebmc.co.uk/Feature.aspx?id=3156
110. van der Putten EP, Snijder CJ. Shoe design for prevention of injuries in sport climbing. Appl Ergon. 2001;32(4):379–87.
111. Schöffl V, Winkelmann HP. [Foot deformations in sport climbers] Fußdeformitäten bei Sportkletterern. D Z Sportmed. 1999;50:73–6.
112. Schöffl V, Schöffl I. Injuries to the finger flexor pulley system in rock climbers – current concepts. J Hand Surg [Am]. 2006;31(4):647–54.
113. Schöffl I, Einwag F, Strecker W, Hennig F, Schöffl V. Impact of taping after finger flexor tendon pulley ruptures in rock climbers. J Appl Biomech. 2007;23:52–62.
114. Bayer T, Schoffl VR, Lenhart M, Herold T. Epiphyseal stress fractures of finger phalanges in adolescent climbing athletes: a 3.0-Tesla magnetic resonance imaging evaluation. Skeletal Radiol. 2013;42(11):1521–5.
115. Hochholzer T, Schöffl V, Bischof B. [Epiphyseal fractures of the middle phalanx in sport climbers] Epiphysenfrakturen der Fingermittelgelenke bei Sportkletterern. Sport Orthop Traumatol. 2002;18:87–92.
116. Robertson N. Improving patient safety: lessons from rock climbing. Clin Teach. 2012;9(1):41–4.

Alpine Skiing and Snowboarding: Current Trends and Future Directions

11

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11.1 Introduction

Skiing and snowboarding are two of the most popular winter sports today. Skiing has existed in one form or another for thousands of years, with the world's oldest skis being dated from between 6300 and 5000 BC [1]. Snowboarding, in contrast, is a more recent sport, with the first snowboard patent awarded in 1965 [1]. During the 2012/2013 ski season, there were 477 ski resorts operating in the United States alone [2], with an estimated 9.67 million active domestic skiers and snowboarders [3]. It is estimated that snowboarders make up between one-third and one-half of participants at most resorts [4, 5]. Both skiing and snowboarding continue to be active on the world stage, both recreationally and competitively. In the 2014 Sochi Olympic Games, several new skiing and snowboarding events were introduced including skiing and snowboarding slopestyle (men's and women's), skiing half-pipe (men's and women's), snowboarding parallel slalom (men's and women's), and women's ski jumping. Skiing and snowboarding, with their ability to travel at high speeds down snow-covered mountains using only the force of gravity, skill, and minimal equipment, offer a freedom unparalleled by most sports. Like most physical activities involving speed and variable conditions, there are risks associated with skiing and snowboarding that cause a substantial number of injuries. This chapter will explore the current state of literature about skiing and snowboarding injuries, examine the most common injuries typically seen in beginners to experts, and address potential strategies to minimize the risks associated with these sports.

11.2 Injuries

Both skiing and snowboarding involve variable conditions, often high speeds, and navigating around other slope users of varying ability level. Unsurprisingly this leads to a fairly high injury rate among participants of both sports. While data concerning these injuries can help to understand the risks involved in these sports, the studies that report on these numbers vary in their methods for obtaining this data, and the data is often retrospective in nature. Some studies base their findings on data collected from on-mountain first aid clinics and ski patrol data, while others collect their data from hospitals near the mountains in question. If an injury occurs on the slope, generally the first responders are professional ski patrollers. Ski patrol on mountain assessments

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has been reported to be reasonably accurate at diagnosing injury, as was suggested in one study where their assessments were demonstrated to be correct or mostly correct 89.5 % of the time [6]. Other studies have shown ski patrollers were effective at identifying the location of an injury, but may misdiagnose the severity of an injury [4]. Many of the studies reporting injury rates have relied on data from on-mountain ski patrol clinics, and this may affect the accuracy of these reports. In addition, a substantial proportion of injured individuals bypass the mountain ski patrol clinics, choosing to either go directly to the nearest hospital or avoid treatment altogether. Up to 40 % of on-mountain injuries may go unreported, and during one season at a Colorado resort (1996–1997), 31 % of skiers and 29 % of snowboarders refused medical attention from ski patrol after an injury [7]. Since skiing and snowboarding are popular activities, participation varies by the individual, and participants may ski everyday of the winter to only once a year. Thus, instead of reporting the number of skiers injured, which would lead to extremely variable data, a useful method of classifying injury rates is the number of injuries per 1000 skier or snowboarder days. While this is the most popular method of reporting on the injury rate in organized sports, some of the studies vary in the method of quantifying their injury rates, which can make cross comparison challenging.

Overall skiing injury rates have been reported to be between 1 and 3/1000 skier days [8, 9]. Snowboarding injury rates appear to be higher than skiing, at 1.16 and 4.2/1000 snowboarder days [10–12]. The different mechanics and equipment involved in skiing and snowboarding lead to very different injury patterns. Skiers tend to have a high incidence of lower extremity injuries, especially knee injuries [4, 5, 12, 13] and thumb injuries [5, 14], while the most frequent injury in snowboarding has consistently been reported to be injury to the wrist, either sprains or fractures [4, 10, 11]. Ankle injuries, both sprains and fractures, are fairly common in snowboarders, but are less common in skiers [9, 10, 15, 16]. Head and spine injuries are also fairly common in both skiing and snowboarding [17].

The vast majority of skiing and snowboarding injuries, up to 70 % [18], are caused by isolated falls due to personal error [4, 18–21]. Collisions with another slope user are often thought to be a significant cause of injury on the slopes, and it is commonly thought that snowboarders, with their different path of traveling down the mountain, increase the risk of collisions [16]. However, the rates of serious injury caused by collisions has consistently been reported to a much smaller cause of injury than isolated falls [4, 16, 18, 21, 22], from as low as 2.4 % [18] to as high as 21 % [19]. The large range in the data is likely due to the great variation in the number of skiers and acreage at different resorts, and resorts with higher densities of skiers, either due to popularity or lack of terrain, will likely have higher rates of collisions. Contrary to popular belief, skiers are more likely to be involved in collisions than snowboarders [4, 5, 16, 18, 23], and skiers are more likely to collide with other skiers than with snowboarders [5]. Falls when landing from a jump are also a cause of a large number of injuries and are more likely to be a cause of injury in snowboarders than skiers [4, 5, 11, 18] (Fig. 11.1).

11.3 Skiing Injuries

The mechanics of skiing involve a separate ski attached to each leg with a binding designed to release in the event of high forces. The independent nature of the two skis means that one ski may move in isolation of the other. During a fall, a ski may catch on the snow and act as a lever arm, creating a torque at the knee. While ski bindings are designed to protect against tibial fracture, they are less effective at protecting the soft tissues of the knee. Consequently, about one-third of all ski injuries involve damage to the soft tissues of the knee [8, 24, 25]. The two most common knee injuries in skiers are medial collateral ligament (MCL) sprains, which can usually be treated non-operatively, and complete ruptures of the anterior cruciate ligament (ACL) which often require surgical intervention [8]. ACL tears in particular, due to their debilitating nature and poor long-term prognostics, are of

Figs. 11.1 Snowboarding jump (Photo by Jack Antal)

special concern. Three distinct mechanisms have been identified as the primary causes of ACL tears in recreational skiers [26–28]. The first type of injury known as the boot-induced anterior drawer (BAID) mechanism of ACL injury occurs from an off-balance landing from a jump. If the skier lands with his weight back, the tails of the skis will strike the snow first. The reaction force from the snow creates a moment which drives the ski tips downward. This causes the boot to apply a "passive anterior drawer load" to the tibia which can eventually strain the ACL to rupture [8, 27, 29]. A second mechanism of injury is known as "flexion-internal rotation" or "phantom foot." This occurs when the skier's weight is centered over the back of their skis, known in skiing terminology as being in the "backseat." The skier then loses his/her balance and sits backward toward the slope. The inside edge of the tail of a ski catches the snow and produces a sudden internal rotation of the hyperflexed knee, which tears the ACL. The third mechanism for ACL tear is "valgus-external rotation" also known as a "forward twisting fall." In this mechanism, the medial edge of the anterior portion of the ski engages the snow, and the skier is propelled forward by their downhill momentum, causing the lower leg to be externally rotated and abducted relative to the thigh [8, 26, 27]. The MCL is thought to be the primary ligament injured in this type of fall, but in 20 % of cases, the ACL is also torn [26, 27].

The phantom foot mechanism of ACL injury was long thought to be the most common cause of ACL injury. However, in the mid-1990s, shorter, specially designed carving skis began to replace traditional longer skis. Since then, the forward twisting fall mechanism has overtaken the phantom foot mechanism as the dominant form of ACL injury in skiers [24, 25, 30]. It is possible that the shorter length of these skis, usually up to the skier's nose or chin instead of above their heads which was common for traditional skis, limits the ability of the tails to catch the snow and internally rotate the leg while the wider nose of carving skis, designed to help initiate a turn, may itself catch the snow and lead to an increase in the valgus-external rotation of the lower leg during a fall. This pattern seems to hold true for elite level skiers as well. In 2009 Bere et al., described three mechanisms of ACL injury observed in World Cup alpine skiers [29]. One of these mechanisms occurred when the skiers landed out of balance with their weight backward from a jump and appeared similar to the BIAD mechanism described in recreational skiers, although the authors suggested there may be multiple loading conditions that could stress the ACL during such a landing in addition to anterior tibial drawer. The other two mechanisms, the "slip-catch" mechanism and "dynamic snowplow," occurred when an out-of-balance skier attempted to reestablish snow contact with a ski and the inside edge of their ski abruptly caught the snow surface, forcing the knee into internal rotation and/or valgus relative to the lower leg [29]. Although the conditions leading up the injury are different, the forces applied to the leg seem to be similar to the forward twisting fall seen primarily in recreational skiers in that the inside edge of their carving skis caused forced internal rotation and valgus of the knee, injuring the ACL. Note that while the forward twisting fall mechanism is also known as the "valgus-external rotation," it is the ski which is being externally rotating while the knee is driven into internal rotation in response.

Knee injuries and especially ACL injuries are several times more common in women than in men [8, 21, 25, 30], possibly due to relative quadriceps weakness in women, lower intercondylar notch dimensions, increased joint laxity, or hormonal differences [8]. In a study of knee injuries of skiers using carving skis, Reudl et al. noted that the bindings did not release in 82 % of falls that resulted in ACL tears in women, while they released in 64 % of similar falls in men [24]. Currently, binding release settings are based on height, weight, foot size, and skier ability, but not gender [31]. It has been suggested that reducing the binding release values by 15 % in female skiers could reduce knee injuries [25].

Another injury unique to skiers compared to snowboarders is a tear of the ulnar collateral ligament (UCL) of the first metacarpophalangeal (MCP) joint [5, 11, 14, 32, 33]. This often occurs when a skier lands on an outstretched hand while holding a ski pole, which causes forced abduction of the thumb and thus ligament damage. This injury is historically so common in skiers that it is also known as "skier's thumb." Depending on the severity of the injury, treatment can range from immobilization and eventually gentle physical therapy to, in the case of avulsion, surgical management [32].

Due to the potential high velocities in skiing, it is unsurprising that various fractures occur, most often to the tibia, though these are much less common than knee soft tissue injuries [11, 12, 14]. A substantial number of head, neck, and spine injuries also occur [11, 12, 14, 34], with head injuries being most common among children [12, 34]. This underlies the importance of helmet use, which will be discussed later in this chapter.

11.4 Snowboarding Injuries

The unique mechanics of snowboarding compared to skiing lead to a different injury pattern than seen in skiers. By far the most common injury seen in snowboarders is a wrist sprain or fracture [4, 9–12, 14]. These make up anywhere from 22 to 37.8 % of all snowboarding injuries [4, 9, 11]. Since snowboarders generally do not carry poles, when they fall they often attempt to catch themselves with an open hand, which puts them at risk for injuring their wrist. The shoulder joint is also a common upper extremity injury in snowboarders, especially in experienced riders [9].

Lower extremity injuries are less common in snowboarders than skiers. When they do occur, the leading leg is injured much more frequently than the trailing leg [10]. The mechanism behind this phenomenon is unknown and requires further investigation [10]. Ankle injuries are slightly more common in snowboarders than in skiers, including both ankle sprains and fractures [9, 10, 15, 16]. One particular ankle injury unique to snowboarding is a fracture to the lateral process of the talus, also known as "snowboarder's ankle." The proposed mechanism from this injury is a combination of compression and forced inversion or dorsiflexion which may occur when landing from a jump [4, 35]. This injury is important to note because it is frequently missed on plain radiographs and misdiagnosed as a severe ankle sprain [4, 11]. However, conservative management of this type of injury, such as that which would likely occur with an ankle sprain misdiagnosis, can lead to significant disability and osteoarthritis if anatomic alignment is not appropriately maintained [4, 35]. Thus, other imaging techniques such as computed tomography or magnetic resonance imaging are recommended if a snowboarder presents to a clinic with an injured ankle after falling from a jump.

Knee ligament tears are much less common in snowboarding than skiing, most likely due to the fact that the nonreleasable binding system in snowboarders also prevents valgus stress from being applied on one leg, as is seen in the forward twisting fall mechanism of ACL tears common in skiers [14]. ACL tears predominantly occur in expert snowboarders during an improper landing from a large jump, called a flat landing. Normally skiers and riders attempting large jumps in a terrain park aim for the sloped transition of the jump, but when a rider misses the transition, either by jumping too far or not far enough, they land on a flat surface with all the force directed vertically through the leg. During such a landing, the flexion moment on the legs would be resisted by quadriceps. This high level of activation of the quadriceps and low activation of the hamstrings could, in combination with a slightly flexed leg, eccentrically load the knee and strain the ACL to rupture [36]. Studies have reported that another time ACL tears sometimes occur is when only one foot is attached to the snowboard [11]. Snowboarders typically ride with one foot attached to the snowboard when loading and unloading from chairlifts and also when traversing a long, flat area. Falls during these times would allow the snowboard to act as a lever arm in a similar manner to skis and have the potential to injure the ACL.

Snowboarders tend to be at a higher risk of spine injuries and head injuries than skiers [14, 17, 37]. This is mostly likely due to the mechanics of snowboarding which allow for falling backward, thus causing spinal and potentially head trauma. These effects seem to be especially pronounced in beginners [17, 37].

11.5 Skill-Specific Differences

The injury patterns in skiers and snowboarders tend to vary greatly depending on the skill of the participant. Beginners in both sports are responsible for the most injuries though this trend is more pronounced in snowboarding where beginners make up 30–60 % of snowboarding injuries but only 18–34 % of skiing injuries [4, 5, 19, 22, 38]. However, some studies suggest that the injuries sustained by experts in both sports may be more severe [39], which makes sense given the higher travel speeds and more advanced terrain utilized by experts. Expert skiers tend to have greater rates of head, trunk, and upper extremity injuries than beginners. Expert snowboarders tend to have lower rates of upper extremity injuries, especially wrist injuries and head injures [19, 39]. When expert snowboarders experience head and neck injuries, they tend to be less severe, while upper extremity injuries tend to be more severe [39]. Expert snowboarders also suffer a disproportionate number of ACL injuries compared to beginners [10]. As noted above, the predominant mechanism for ACL injuries in snowboarders is jumping related, an activity far more likely to be attempted by experts.

11.6 Risk Factors

Skiing and snowboarding are both high-velocity sports and contain inherent risks. However, there are many factors, both internal and external, that can increase the level of risk (Fig. 11.2).

A common factor in injury is skiing or snowboarding past one’s ability level. Attempting a trail above one’s abilities is likely to increase the potential for a fall. Skiing on a run that is too challenging also could have the effect of causing the skier or snowboarder to increase their speed more rapidly than is comfortable and cause them to lose control. Hasler et al. identified “low readiness for speed” as a common cause of injury in snowboarders [40]. Such a situation could arise on a slope that is too steep or too icy for a beginner or intermediate rider or skier.

Skiing and snowboarding are physically demanding sports that require careful focus, awareness, and good form to perform safely, and thus, it is unsurprising that fatigue could increase the risk of injury. Studies show that the majority of ski injuries occur in the afternoon, when skiers and snowboarders are more fatigued [14]. This

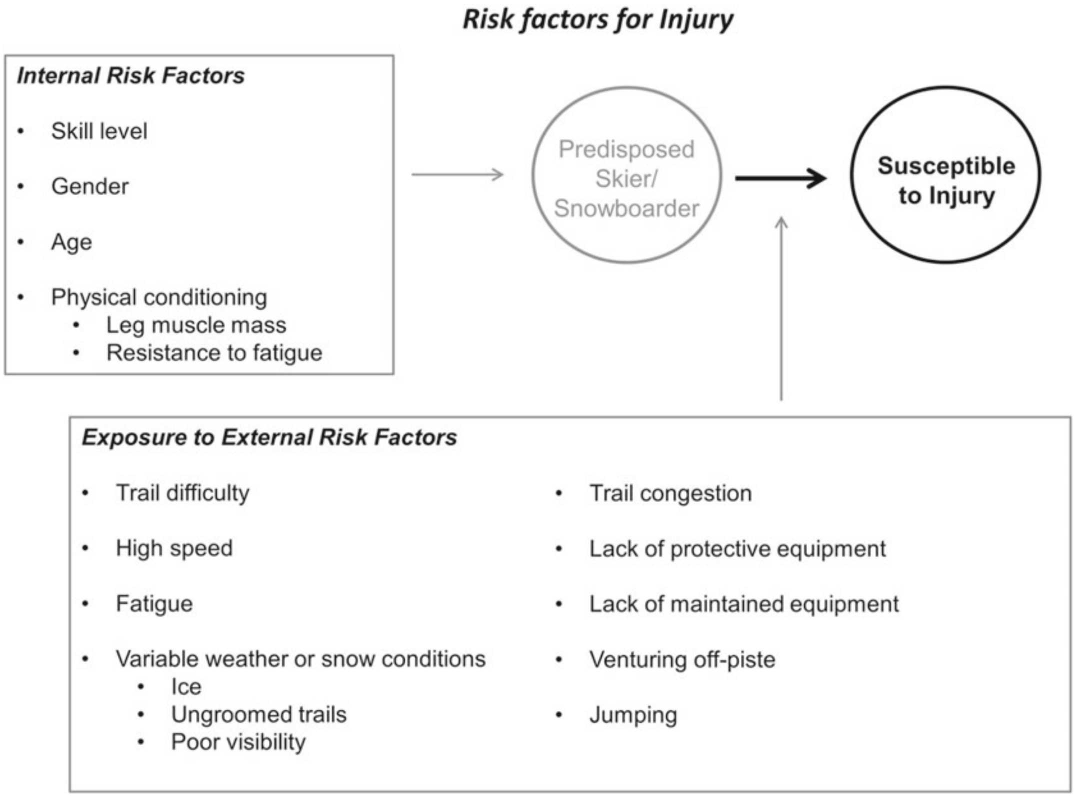

Fig. 11.2 Internal and external risk factors present in skiing and snowboarding

trend is even present in professional alpine skiers, as most injuries occur during the last fourth of the race [13]. Fatigue has also been shown to have a negative effect on balance [13, 41, 42]. Finally fatigue may cause reaction time to decrease, which could lessen the ability to absorb an impact from an irregularity in the trail or to navigate an obstacle.

High traveling speed has been reported by several sources to be a risk factor for injury [13, 43, 44]. While one source did not report any increase in injury rates in World Cup downhill skiing events with increased travel velocities, the authors suggested that speed could have major impacts on the injury risk in general, which would reduce the ability to anticipate rough terrain and turns, especially when traveling off-piste [40]. Between variable snow conditions, unmarked obstacles, and unpredictable other slope users, a skier and snowboarder must remain in control and able to adapt to their surroundings. However, traveling at a high speed, especially beyond their ability level, reduces the amount of time possible to adjust to these changing conditions. Speed also increases the force of any impact, whether during a fall or with another slope user.

As mentioned above, skiing and snowboarding take place outdoors and while resorts may have some control over snow conditions, for example, creating a more consistent surface by grooming a trail, conditions can change rapidly due to changing temperatures, precipitation, or ski traffic. Soft snow can rapidly turn into an irregular, bumpy surface which can be challenging to navigate especially for beginners. The risk of sustaining a concussion has also been reported to be 2.5 times greater on ungroomed or rough snow compared with soft snow [17]. Skier traffic can scrape off snow and expose ice. Icy conditions have been identified as risk factors in injury [40, 45]. Ice can make it difficult to turn in order to control speed and direction and can also harden the snow, creating a less forgiving surface in the event of a fall. Poor weather and visibility have also been suggested to play a role in the risk of injury. This can be explained by the fact that poor visibility would limit the skier or snowboarder's ability to navigate around obstacles or prepare for snow irregularity [40, 45].

Finally, the choice of equipment can alter the risk of injury. Using unfamiliar equipment, as is common with beginners using rentals, may prevent a skier or snowboarder from performing optimally. Older equipment may not have effective safety features and, if not maintained, may also perform worse on hard and icy conditions. Specific to skiing, bindings which are not properly adjusted for the skiers' weight and ability level could either not release early enough during a fall, which could create a torque on the knee with the potential to create injury, or release too soon during normal skiing, causing a fall on their own [20, 46].

11.7 Injury Prevention

Due to the high medical costs incurred by skiing and snowboarding injury, it is important to investigate how we can reduce the number and severity of these injuries. Most studies that have examined strategies to reduce the number of injuries have focused on equipment or behavioral approaches [33].

Head injuries are an important area of concern. While they account for between 3 and 15 % of all injuries, they make up 50–88 % of all skiing and snowboarding fatalities [17]. Helmets are a common-sense protective measure, the effects of which have been investigated in multiple studies. Helmets may reduce the risk of head injuries by 15–60 % [34, 47]. One criticism of helmets is that they might add additional weight to the head and thereby increase the risk of neck injury, a concern especially for children where their head already constitutes a large percentage of their weight. While one study suggested a possible slight increase in risk for neck injury [47], other studies have found no increase in neck injuries in adults [34, 48, 49] or children under 13 [50]. Another concern raised about helmets is the possibility of risk compensation, in which a skier or snowboarder will ride more recklessly due to the added sense of protection imparted by the helmet. However, studies have shown that wearing a helmet does not increase the risk of non-head-related injuries, and thus, no evidence exists for risk compensation [47, 51, 52]. Based on these results, we universally recommend that skiers and snowboarders wear helmets. This is an area where ski resorts can focus their efforts to reduce injuries, such as by requiring children under a certain age to use a helmet. Many provinces in Austria have established mandatory helmet laws for children and adolescents under the age of 16. Interestingly, Ruedl et al. reported that provinces with legislation were shown to increase their helmet use by a smaller percentage than provinces without legislation. Thus, they concluded that mandatory laws may increase rates of helmet use in provinces where use is already low, but public education may be as effective as mandatory laws [53]. Helmet use was also observed to be lower in adolescents 16 and older in provinces where helmets were not mandatory [53]. A more recent study of Austrian children reported that helmet laws in combination with an educational campaign increased self-reported helmet use to 99 % for children under 16, which then decreased to 91 % for children 16 and older. Interestingly enough, the rate of helmet use for adolescents over 16 was lower in provinces where helmet use laws were in effect than in provinces where they were not, suggesting that making helmets mandatory decreases compliance in children above the restricted age, where they may view the option to not wear helmets as a new freedom [54]. Several public education campaigns to promote helmet use are already in existence, for example, the "Lids on Kids" campaign promoted by the National Ski Areas Association (NSAA) in the United States, which encourages the use of helmets in children. Due in part to these campaigns, helmet use in skiing and snowboarding is higher than it has ever been in the United States, with 70 % of all skiers and snowboarders, 80 % of skiers and snowboarders under the age of 18, and nearly 90 % of children ages 9 and under wearing them [55]. Note that these rates of helmet use are much lower than in Austria, but also note that the overall helmet use rates in Austria were higher than the United States in all provinces, regardless of mandatory helmet laws, suggesting a cultural difference in attitudes toward helmet use between the two countries. Whether mandatory helmet laws are the best method for increasing helmet use is a topic for debate.

Since the most common injuries in snowboarders are wrist sprains and fractures, wrist guards have been investigated as a potential tool to reduce the rate of these injuries. Wrist guards have been shown to reduce the risk of wrist and forearm injuries between 52 and 82 % [56–58]. Despite this, very few snowboarders choose to wear them. While wrist guards may decrease the risk of wrist injuries, some studies have found an increase in shoulder and elbow injuries when wrist guards are used [56]. Landing on the forearm with an extended elbow while wearing a wrist guard may make the arm act as a lever with the fulcrum at the point of impact and transfer a torque to the shoulder joint. Furthermore, the studies that have looked at the use of wrist guards have generally ignored the many different designs of wrist guards, and thus, not enough study has been done to say which, if any wrist guards provide the most protection while reducing the risk of shoulder injury. At this time there is not enough evidence to universally recommend the use of wrist guards for experienced snowboarders where the risk of wrist injuries is already relatively low, and more research should be done to determine if they should be recommended for beginners, who are at the highest risk of wrist injury.

As noted above, properly maintained equipment, especially properly adjusted ski bindings, can help reduce the risk of injury [20, 46]. Properly adjusted bindings will release when the forces generated by a fall are sufficient, and bindings that are too tight will not release in the event of a fall and can potentially generate enough torque to injure a skiers' knee. Regularly sharpened skis can more easily maintain purchase and help skiers maintain control on hard and icy conditions, which have been noted as a risk factor in injury [40, 45].

Another substantial cause of injury is overestimating one's ability level or not properly assessing the snow conditions. Fortunately, virtually all ski resorts in North America and most throughout the world grade and mark their trails with a difficulty rating from beginner to advanced terrain. While this is important, the categories can be broad and the difference, for example, between a beginner and intermediate trail is relative to the other trails on the mountain. Furthermore, conditions can easily change what would normally be an easy run into a hazardous one. Many mountains post daily condition reports which state whether a trail is groomed, ungroomed, has fresh powder, or other important slope information which can give a skier or rider an idea of the conditions prior to attempting a trail. Another way that this could be addressed is to include training about assessing conditions and also understanding one's limits when taking lessons. Counterintuitively, taking ski or snowboard lessons has not been shown to decrease the risk of injury [38, 46]. This may be because lessons tend to be focused on the rapid acquisition of skill as opposed to safety education and that individuals who take lessons often take them sporadically which may not be enough to instill safe habits. Ski lessons could potentially improve the rates of injury by placing an emphasis on acquiring this knowledge as well as learning physical techniques.

Other training methods to reduce injury may be of interest. Ettlinger et al. demonstrated that injuries to the ACL could be reduced by 62 % using a training session in which participants were involved in interactive video and physical instruction to identify movement patterns which could contribute to the phantom foot mechanism of ACL injury [59]. Using instructional ski videos alone, Jørgensen et al. were able to show a 30 % reduction in ski injuries compared to those who had not been shown the videos [60]. Since the publication of these articles, the sport of skiing has evolved substantially, especially with the advent of carving skis in the mid-1990s which altered the pattern of ACL injuries such that the forward twisting fall mechanism of ACL tear is now the more dominant. However, these two approaches could be adapted using modern ski equipment, with focus on the forward twisting fall mechanism of ACL tear. If these methods prove to be effective, instructional videos could be spread using the internet and social media services to reach the largest number of skiers.

Finally, one area that could be addressed is musculoskeletal conditioning regimens and neuromuscular training specific to skiing and snowboarding. A similar strategy has been implemented in soccer using a program known as the “FIFA 11+” which includes cardiovascular conditioning, core and leg strength, and balance and agility, can be completed in 20 min as a warm-up prior to a match or training, and has been shown to reduce training injuries by 37 %, match injuries by 29 %, and severe injuries by 50 % [61]. A skiing-specific training regimen was suggested by Morrissey in 1987 which included stretches, resistance, and cardiovascular training specific to the activities involved in skiing [62]. While parts of this training could be applied to modern skiing, with the advent of shaped skis, the mechanics and musculature involved in skiing are likely very different. Furthermore, to our knowledge, nothing similar has been proposed for the sport of snowboarding, which utilizes completely different mechanics than skiing. Such neuromuscular training could be useful for preventing skiing and snowboarding injuries. However, there currently exists minimal information in the literature that suggests conditioning or strength training routines or even individual exercises that could be used to prevent injury in skiing or snowboarding [33]. Further research must be conducted to identify exercises which could be incorporated into neuromuscular training programs specific for skiing and snowboarding and would ideally include activities that can be performed easily in ski and snowboard boots prior to taking the first run of the day.

11.7.1 Extreme Terrain

11.7.1.1 Off-Piste Terrain

The vast majority of skiing and snowboarding accidents take place on maintained slopes run by ski resorts (“on-piste”). However, it is common for advanced and expert skiers and snowboarders to venture off the relative safety of these maintained slopes into unmaintained trails in search of fresher snow, more challenging terrain, and fewer crowds. This is known as going “off-piste.” While most of the normal risks of alpine skiing and snowboarding are still present when venturing off trail, additional risks present themselves, including natural hazards such as the risk of avalanche, cliffs, rocks, and other unmarked obstacles, as well as additional risks encountered when traveling in isolated regions in the mountains such as frostbite, hypothermia, dehydration, fatigue, acute mountain sickness, and sunburn.

Many ski resorts have large areas of ungroomed terrain geared toward the advanced and expert skiers seeking this experience. These areas are usually avalanche controlled, accessible by ski lifts, and patrolled by professional ski patrollers. For those individuals who seek a more remote experience with the possibility of untouched snow, backcountry skiing and snowboarding have become increasingly popular. Traditionally, backcountry skiing and snowboarding utilize specialized equipment to ascend a trail, such as snowshoes or skis equipped with specialized bindings and “skins,” removable coverings which provide traction on snow. “Split-boards,” specialized snowboards that can be separated lengthwise and used in a similar manner as cross-country skis while ascending a trail and then reattached when descending, are increasingly popular among snowboarders as well. This equipment allows access to terrain inaccessible by ski lift and promises a more remote experience. Other skiers and snowboarders use services such as chartered helicopters (known as the activity of heli-skiing) or snowcats, vehicles with an enclosed cab and tracks for traveling on snow. Regardless of the method of accessing the terrain, backcountry skiing and snowboarding carry a high level of risk.

Ski resorts that receive a large amount of natural snow hire trained personnel for the purpose of avalanche prevention. These professionals detonate strategic explosives and dislodge any slides prior to opening those areas to the public, thus minimizing, though not completely eliminating, the risk of avalanche inside resort boundaries. Backcountry skiers and riders have no such protection and must rely on personal knowledge acquired through avalanche safety training and personal experience to mitigate their risk. Deaths due to avalanches are most often caused by asphyxia from snow burial, although trauma from impact with debris such as trees and rocks or due to being swept off a cliff also contributes to avalanche fatalities [63, 64]. The chance of surviving being buried by an avalanche has been estimated to be 92 % if the survivor is rescued within 15 min and then drops to 30 % at 35 min [65]. Thus, rapid rescue in the event of a snow burial is crucial. Most backcountry travelers carry specialized equipment such as avalanche transceivers, probes or telescopic poles, and lightweight snow shovels which are necessary to quickly locate and extricate a buried partner. These systems have been shown to significantly increase the chances of survival in the case of complete burial [66]. Other specialized equipment has been developed to improve avalanche survival including the AvaLung (Black Diamond Limited, Salt Lake City, UT) which helps to create an artificial air pocket in the event of a burial and deployable air bags such as the ABS system (ABS Peter Aschauer GmbH, Gräfelfing, Germany) that help an individual remain on the surface of the snow during a slide. Deployable air bags have been reported to significantly increase the chance of survival in an avalanche [66], and tests of the AvaLung system have been reported to maintain an adequate breathing supply for up to 60 min when used properly [67]. While a combination of these devices is recommended for backcountry travelers, personal avalanche training and knowledge of current avalanche conditions are the first line of defense to avoid such a situation.

Another cause of fatalities among skiers and snowboarders venturing off-piste is non-avalanche-related snow immersion death (NARSID), or more appropriately snow immersion asphyxiation. This typically occurs when a skier or snowboarder falls upside down into a deep hole surrounding a tree, known as tree well, although it may occur in deep snowbanks absent from trees as well. The skier or snowboarder then is unable to extricate themselves from the well and asphyxiates [68]. Preventative measures to avoid accidents of this sort are similar to those recommended for avalanche safety, such as skiing with a beacon, probe, and shovel and always remaining within visual and vocal range of a buddy.

It is clear that backcountry travel poses additional safety concerns to the sports of skiing and snowboarding in addition to the risks already attached to simply riding down a groomed trail. The terrain accessed by backcountry travel can be more extreme than that encountered on-piste, and thus, injuries sustained can sometimes be equally extreme in nature. To illustrate this point, we present the case of a 55-year-old male skier. The patient reported that he had been dropped at the top of a run with two friends while heli-skiing when the cornice they were standing on collapsed, causing him to fall 800 feet down a glacier. The patient suffered a closed knee dislocation of the left leg. He presented with complete ACL, PCL, MCL, posterolateral corner, and MPFL tears, as well as bucket-handle tears of both the medial and lateral menisci (Figs. 11.3 and 11.4).

Unsurprisingly, these injuries required major surgical repair and long-term rehabilitation. This case illustrates the trauma that can occur even for experienced skiers and snowboarders when traveling on extreme and unpredictable terrain in the backcountry. Thus, proper gear, knowledge of conditions, and avalanche safety are critical when venturing off-piste.

11.7.2 Terrain Parks

Terrain parks are designated areas on the mountain which contain man-made features such as jumps, rails, boxes, and half-pipes for the performance of technical maneuvers such as grinds, spins, grabs, and flips. These areas became common in the mid-1990s and have continued to increase in popularity, primarily among snowboarders, but increasingly among skiers as well. Terrain parks became especially popular with snowboarders after the Nagano Olympics in 1998, the first Olympics to feature a snowboarding half-pipe event. The popularity of terrain parks among skiers may begin to increase as well, as the 2014 Sochi Olympics was the first to

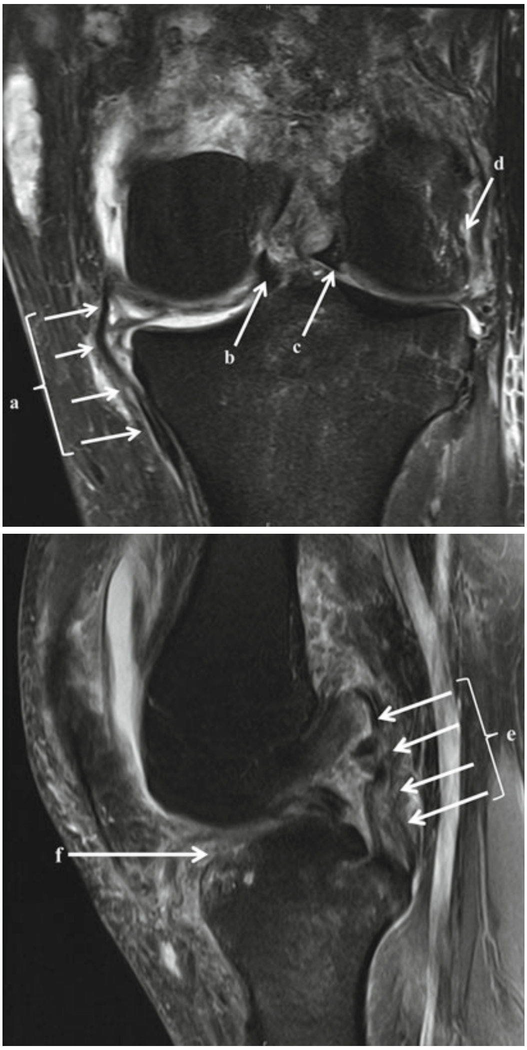

Fig. 11.3 MRI images of 55-year-old injured skier with total knee dislocation. *Top*: coronal view. Damaged structures are as follows: (*A*) MCL tear, (*B*) medial meniscus bucket-handle tear, (*C*) lateral meniscus bucket-handle tear, and (*D*) popliteus tendon tear. *Bottom*: sagittal view. Damaged structures are as follows: (*E*) PCL tear and (*F*) ACL tear

include a skiing half-pipe event as well as skier and snowboarder slopestyle events. Generally speaking, the average demographic of terrain parks seems to be young, male snowboarders [69], of which all three factors are associated with risk-taking behaviors and consequently injury rates. Furthermore, taking off and landing jumps in skiing and snowboarding are associated with a high risk of injury [4, 11, 70], and due the nature of the tricks, which often involve high velocities and often rotational forces, it would be expected that these areas would have a high incidence of injury and possibly a unique injury pattern as well. In fact, the data suggests that the overall injury rate may actually be lower in terrain parks than other parts of the mountain [71] but injuries that do occur may be more severe and result in more ambulation. These studies found that fractures, concussions, and injuries to the head face and back were more common in terrain parks than on other slopes [69, 71, 72]. Another study, however, disagreed with their findings and found that both terrain park users and non-terrain park users had similar rates of hospital admission and total hospital length of stay and the majority of injured patients were discharged home in both groups, suggesting that the injuries sustained in terrain parks do not seem to be more severe than other injuries [73]. Interestingly, the rate of advanced and expert skiers and snowboarders injured in terrain parks is higher than on other parts of the mountain, while the rate of injuries of beginners, possibly recognizing their lack of skill and avoiding park features all together, is quite low [69, 71, 72]. The high number of injuries among experts is due to the fact that this demographic likely attempts larger jumps and more challenging tricks, which could lead to higher energy transfer during crashes [72]. This trend is far different than for the general skiing and snowboarding population where the highest injury rates occur among beginners [4, 5, 19, 22, 38]. In addition to the typical pattern of a high rate of upper extremity injury in snowboarders and high rate of lower extremity injury in skiers, snowboarders in terrain parks were also more likely to injure the chest, upper abdomen, and shoulder, while skiers also tended to injure the face and hip [69].

Multiple strategies have been attempted by resorts to help reduce the number of terrain park injuries. Some methods suggested by authors include creating terrain parks for beginners with smaller features, making helmets mandatory in these areas, and creating training programs for terrain park skiing and snowboarding to reduce the risk of injury [69, 71]. Fortunately, in the

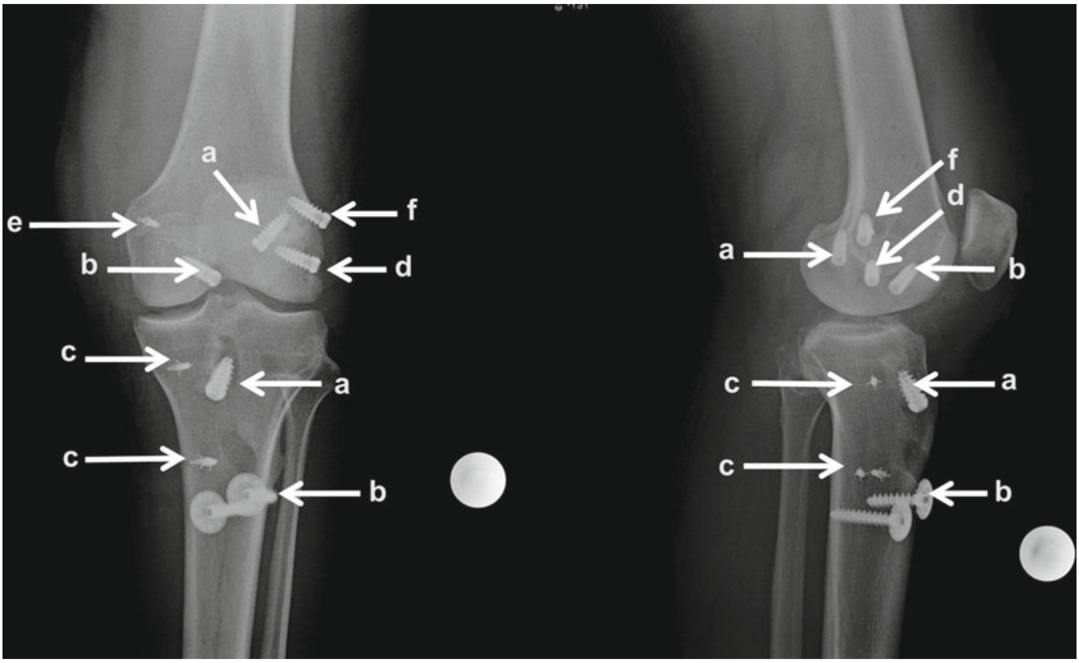

Fig. 11.4 X-ray image of reconstructed knee. The following indicate sites of reconstruction or repair (note that we are only pointing out metallic fixation, and the MCL femur, FCL fibula, and popliteofibular ligament and popliteus on the tibia are translucent bioabsorbable screws): (*A*) ACL, (*B*) PCL, (*C*) MCL, (*D*) popliteus, (*E*) POL, and (*F*) FCL

United States at least, some measures are being taken to address some of these risks. The "Smart Style" safety initiative promoted by the National Ski Areas Association promotes education about terrain park safety and etiquette in the form of signs and also safety videos. This initiative also encourages grading terrain park features by size, which helps to create a logical progression and alleviate the issue of terrain park novices becoming injured by attempting maneuvers far above their skill level [74]. In addition, due to the technical nature of these maneuvers, many of which would benefit from professional instruction, some ski and snowboard instructors' associations, such as the Professional Ski Instructors Association (PSIA) and American Association of Snowboard Instructors (AASI), offer certifications to train instructors how to effectively teach these skills [75]. This has the added benefit of further emphasizing safety education to riders. Many mountains require the use of helmets in the terrain parks and some even require that participants who want to use terrain parks purchase a special pass and watch a training video prior to entering the parks. These approaches are all fairly recent however, and not enough study has been conducted to evaluate whether these measures will reduce the rates or severity of injury in the terrain park.

11.7.3 Future Directions

While skiing and snowboarding have been the subject of extensive study, many questions remain unanswered about how to most effectively address the high risk of injury that a typical skier and snowboarder faces. As described in the preceding sections, more information must be obtained about training and education programs to prevent ACL injury in skiers and research into protective equipment such as wrist guards. Another issue is how to most effectively encourage the general populous, who may only ski for a single weekend in a year and may not be educated in these matters, to adopt safe habits on the mountain and wear protective equipment such as helmets and, should they prove beneficial, wrist guards. One possible avenue is to ensure that safety information is emphasized in ski lessons. Many children are involved in season-long snow sports programs, and this would be a good area to increase education about helmet use and to also put into practice ACL injury prevention training. Some of these programs already require the use of helmets for all children involved. Vail Resorts in the United States took another approach and now requires that all employees wear helmets, hoping that seeing high-level ski instructors, ski patrol, and other employees wearing helmets will have the effect of setting an example and encourage public adoption of helmets. Whether these programs will help to reduce severe head trauma remains to be seen.

Most skiers and snowboarders spend a large portion of their time on the mountain waiting in lines to ride the chairlift and sitting on the chairlift itself. Another possible strategy to promote safety awareness would be to post safety education, such as helmet awareness information, on signage throughout the mountain, in the lodges, in the lift lines, and on chairlift towers. Most mountains currently use these areas for advertisement space, and some of these signs could easily be converted to educational purposes. Videos describing ACL injury prevention, which as described above have been effective in the past to reduce knee injuries, could be placed in some of the longer lift lines, effectively reaching a large, captive audience. Finally, mountains could set aside space at the base for individuals to perform warm-up exercises and provide information detailing neuromuscular training exercises specific for skiing and snowboarding as described above.

Some of these strategies could be implemented immediately, while others, such as the warm-up area, require more research before they can be implemented. These approaches require the cooperation of the ski resorts themselves, but with the encouragement of the medical community, as well as public support, most are feasible and could help reduce the number of injuries that occur due to skiing and snowboarding.

Conclusions

Skiing and snowboarding are extremely popular sports but come with a relatively high risk of severe injury for the average individual. Risk factors that can increase this potential for injury include skiing at high speeds, skiing above one's ability level, poor snow conditions, and fatigue. The risk of serious injury can be mitigated, and most literature that suggests strategies for reducing risk focuses on both on-mountain policies such as setting up enforcement of slow-speed zones, posting signage detailing safety information, and also equipment strategies, such as encouraging the use of helmets. Strength and conditioning strategies, as well as video and training protocols, could be beneficial to help reduce the rate of injury, but further research is needed in these areas.

References

1. International Ski Federation. History of skiing. n.d. [cited 2014 April 25, 2014]; Available from: http://history.fis-ski.com/uk/background.html.
2. Hawks T. U.S. Ski resorts in operation during the 2012/13 season. 2013 [cited 2014 April 25, 2014]; Available from: http://www.nsaa.org/media/149399/Number_of_Ski_Areas_by_Season_12.13.pdf.
3. National Ski Areas Association. Total active domestic skiers/snowboarders: 1996/97 to 2012/2013. 2013 [cited 2014 April 25, 2014]; Available from: http://www.nsaa.org/media/175155/Participants2013.pdf.
4. Bladin C, McCrory P, Pogorzelski A. Snowboarding injuries: current trends and future directions. Sports Med. 2004;34(2):133–9.
5. Davidson TM, Laliotis AT. Snowboarding injuries, a four-year study with comparison with alpine ski injuries. West J Med. 1996;164(3):231–7.
6. Kupper T, et al. Qualified rescue by ski patrols – safety for the skier. Int J Sports Med. 2002;23(7):524–9.
7. Idzikowski JR, Janes PC, Abbott PJ. Upper extremity snowboarding injuries. Ten-year results from the Colorado snowboard injury survey. Am J Sports Med. 2000;28(6):825–32.
8. Rossi MJ, Lubowitz JH, Guttmann D. The skier's knee. Arthroscopy. 2003;19(1):75–84.
9. Made C, Elmqvist LG. A 10-year study of snowboard injuries in Lapland Sweden. Scand J Med Sci Sports. 2004;14(2):128–33.
10. Wijdicks CA, et al. Injuries in elite and recreational snowboarders. Br J Sports Med. 2014;48(1):11–7.
11. Kim S, et al. Snowboarding injuries: trends over time and comparisons with alpine skiing injuries. Am J Sports Med. 2012;40(4):770–6.

12. Hagel BE, et al. Injuries among skiers and snowboarders in Quebec. Epidemiology. 2004;15(3):279–86.
13. Gilgien M, et al. Mechanics of turning and jumping and skier speed are associated with injury risk in men's World Cup alpine skiing: a comparison between the competition disciplines. Br J Sports Med. 2014;48(9):742–7.
14. Abu-Laban RB. Snowboarding injuries: an analysis and comparison with alpine skiing injuries. CMAJ. 1991;145(9):1097–103.
15. Yamagami T, Ishihara H, Kimura T. Clinical features of snowboarding injuries. J Orthop Sci. 2004;9(3):225–9.
16. Sutherland AG, Holmes JD, Myers S. Differing injury patterns in snowboarding and alpine skiing. Injury. 1996;27(6):423–5.
17. Ackery A, et al. An international review of head and spinal cord injuries in alpine skiing and snowboarding. Inj Prev. 2007;13(6):368–75.
18. Xiang H, et al. Skiing- and snowboarding-related injuries treated in U.S. Emergency departments, 2002. J Trauma. 2005;58(1):112–8.
19. Ogawa H, et al. Skill level-specific differences in snowboarding-related injuries. Am J Sports Med. 2010;38(3):532–7.
20. Ekeland A, Holtmoen A, Lystad H. Lower extremity equipment-related injuries in alpine recreational skiers. Am J Sports Med. 1993;21(2):201–5.
21. Macnab AJ, Cadman R. Demographics of alpine skiing and snowboarding injury: lessons for prevention programs. Inj Prev. 1996;2(4):286–9.
22. Bladin C, Giddings P, Robinson M. Australian snowboard injury data base study. A four-year prospective study. Am J Sports Med. 1993;21(5):701–4.
23. Sulheim S, et al. Risk factors for injuries in alpine skiing, telemark skiing and snowboarding–case-control study. Br J Sports Med. 2011;45(16):1303–9.
24. Ruedl G, et al. ACL injury mechanisms and related factors in male and female carving skiers: a retrospective study. Int J Sports Med. 2011;32(10):801–6.
25. Burtscher M, et al. Effects of modern ski equipment on the overall injury rate and the pattern of injury location in Alpine skiing. Clin J Sport Med. 2008;18(4):355–7.
26. Natri A, et al. Alpine ski bindings and injuries. Current findings. Sports Med. 1999;28(1):35–48.
27. Jarvinen M, et al. Mechanisms of anterior cruciate ligament ruptures in skiing. Knee Surg Sports Traumatol Arthrosc. 1994;2(4):224–8.
28. Randjelovic S, et al. Injury situations in Freestyle Ski Cross (SX): a video analysis of 33 cases. Br J Sports Med. 2014;48(1):29–35.
29. Bere T, et al. Mechanisms of anterior cruciate ligament injury in World Cup alpine skiing: a systematic video analysis of 20 cases. Am J Sports Med. 2011;39(7):1421–9.
30. Ruedl G, et al. Distribution of injury mechanisms and related factors in ACL-injured female carving skiers. Knee Surg Sports Traumatol Arthrosc. 2009;17(11):1393–8.
31. International Organization for Standardization, Assembly, adjustment and inspection of an alpine ski/binding/boot (S-B-B) system, in ISO 11088. Geneva; 2006.
32. Anderson D. Skier's thumb. Aust Fam Physician. 2010;39(8):575–7.
33. Hebert-Losier K, Holmberg HC. What are the exercise-based injury prevention recommendations for recreational alpine skiing and snowboarding? A systematic review. Sports Med. 2013;43(5):355–66.
34. Cusimano MD, Kwok J. The effectiveness of helmet wear in skiers and snowboarders: a systematic review. Br J Sports Med. 2010;44(11):781–6.
35. McCrory P, Bladin C. Fractures of the lateral process of the talus: a clinical review. "Snowboarder's ankle". Clin J Sport Med. 1996;6(2):124–8.
36. Davies H, et al. Anterior cruciate ligament injuries in snowboarders: a quadriceps-induced injury. Knee Surg Sports Traumatol Arthrosc. 2009;17(9):1048–51.
37. Yamakawa H, et al. Spinal injuries in snowboarders: risk of jumping as an integral part of snowboarding. J Trauma. 2001;50(6):1101–5.
38. Langran M, Selvaraj S. Snow sports injuries in Scotland: a case-control study. Br J Sports Med. 2002;36(2):135–40.
39. Goulet C, et al. Self-reported skill level and injury severity in skiers and snowboarders. J Sci Med Sport. 2010;13(1):39–41.
40. Hasler RM, et al. Are there risk factors for snowboard injuries? A case-control multicentre study of 559 snowboarders. Br J Sports Med. 2010;44(11):816–21.
41. Simoneau M, Begin F, Teasdale N. The effects of moderate fatigue on dynamic balance control and attentional demands. J Neuroeng Rehabil. 2006;3:22.
42. Qu X, Nussbaum MA, Madigan ML. Model-based assessments of the effects of age and ankle fatigue on the control of upright posture in humans. Gait Posture. 2009;30(4):518–22.
43. Sporri J, et al. Perceived key injury risk factors in World Cup alpine ski racing-an explorative qualitative study with expert stakeholders. Br J Sports Med. 2012;46(15):1059–64.
44. Florenes TW, et al. Injuries among male and female World Cup alpine skiers. Br J Sports Med. 2009;43(13):973–8.
45. Bouter LM, Knipschild PG, Volovics A. Personal and environmental factors in relation to injury risk in downhill skiing. Int J Sports Med. 1989;10(4):298–301.
46. Goulet C, et al. Risk factors associated with alpine skiing injuries in children. A case-control study. Am J Sports Med. 1999;27(5):644–50.
47. Hagel BE, et al. Effectiveness of helmets in skiers and snowboarders: case-control and case crossover study. BMJ. 2005;330(7486):281.
48. Mueller BA, et al. Injuries of the head, face, and neck in relation to ski helmet use. Epidemiology. 2008;19(2):270–6.
49. Sulheim S, et al. Helmet use and risk of head injuries in alpine skiers and snowboarders. JAMA. 2006;295(8):919–24.

50. Macnab AJ, et al. Effect of helmet wear on the incidence of head/face and cervical spine injuries in young skiers and snowboarders. Inj Prev. 2002;8(4):324–7.
51. Hagel B, et al. The effect of helmet use on injury severity and crash circumstances in skiers and snowboarders. Accid Anal Prev. 2005;37(1):103–8.
52. Ruedl G, et al. Self reported risk taking and risk compensation in skiers and snowboarders are associated with sensation seeking. Accid Anal Prev. 2012; 48:292–6.
53. Ruedl G, et al. Impact of a ski helmet mandatory on helmet use on Austrian ski slopes. J Trauma. 2011; 71(4):1085–7.
54. Burtscher M, Ruedl G, Nachbauer W. Effects of helmet laws and education campaigns on helmet use in young skiers. Paediatr Child Health. 2013;18(9):471–2.
55. Byrd D. Ski & snowboard helmet use sets record. 2013 [cited 2014 April 25, 2014]; Available from: http://www.nsaa.org/media/174893/Helmet_Fact_Sheet_10_3_2013.pdf.
56. Hagel B, Pless IB, Goulet C. The effect of wrist guard use on upper-extremity injuries in snowboarders. Am J Epidemiol. 2005;162(2):149–56.
57. Ronning R, et al. The efficacy of wrist protectors in preventing snowboarding injuries. Am J Sports Med. 2001;29(5):581–5.
58. Russell K, Hagel B, Francescutti LH. The effect of wrist guards on wrist and arm injuries among snowboarders: a systematic review. Clin J Sport Med. 2007;17(2):145–50.
59. Ettlinger CF, Johnson RJ, Shealy JE. A method to help reduce the risk of serious knee sprains incurred in alpine skiing. Am J Sports Med. 1995;23(5):531–7.
60. Jlrgensen U, et al. Reduction of injuries in downhill skiing by use of an instructional ski-video: a prospective randomised intervention study. Knee Surg Sports Traumatol Arthrosc. 1998;6(3):194–200.
61. Bizzini M, Junge A, Dvorak J. Implementation of the FIFA 11+ football warm up program: how to approach and convince the Football associations to invest in prevention. Br J Sports Med. 2013;47(12):803–6.
62. Morrissey MC, et al. Conditioning for skiing and ski injury prevention. J Orthop Sports Phys Ther. 1987;8(9):428–37.
63. Boyd J, et al. Patterns of death among avalanche fatalities: a 21-year review. CMAJ. 2009;180(5):507–12.
64. Brugger H, et al. Causes of death from avalanche. Wilderness Environ Med. 2009;20(1):93–6.
65. Falk M, Brugger H, Adler-Kastner L. Avalanche survival chances. Nature. 1994;368(6466):21.
66. Brugger H, et al. The impact of avalanche rescue devices on survival. Resuscitation. 2007;75(3):476–83.
67. Radwin MI, Grissom CK. Technological advances in avalanche survival. Wilderness Environ Med. 2002; 13(2):143–52.
68. Van Tilburg C. Non-avalanche-related snow immersion deaths: tree well and deep snow immersion asphyxiation. Wilderness Environ Med. 2010;21(3):257–61.
69. Brooks MA, Evans MD, Rivara FP. Evaluation of skiing and snowboarding injuries sustained in terrain parks versus traditional slopes. Inj Prev. 2010;16(2):119–22.
70. Bakken A, et al. Mechanisms of injuries in World Cup Snowboard Cross: a systematic video analysis of 19 cases. Br J Sports Med. 2011;45(16):1315–22.
71. Russell K, et al. Characteristics of injuries sustained by snowboarders in a terrain park. Clin J Sport Med. 2013;23(3):172–7.
72. Goulet C, et al. Risk factors associated with serious ski patrol-reported injuries sustained by skiers and snowboarders in snow-parks and on other slopes. Can J Public Health. 2007;98(5):402–6.
73. Moffat C, et al. Terrain park injuries. West J Emerg Med. 2009;10(4):257–62.
74. National Ski Areas Association. Terrain park safety; 2012 [cited 2014 April 25, 2014]; Available from: http://www.terrainparksafety.org/.
75. PSIA/AASI Northwest. Freestyle specialist; 2013 [cited 2014 April 25, 2014]; Available from: http://www.psia-nw.org/education/freestyle-specialist/.

Extreme Mountain Biking Injuries

12

Johannes Becker and Philipp Moroder

12.1 Introduction

In the last decades, "extreme mountain biking" (EMB) has become a popular extreme sport introducing many subdisciplines such as downhill mountain biking (DMB) or freeride (FR) which draw increasing numbers of participants at both competitive and noncompetitive level. It is performed during summer in countries all over the world, especially in mountainous areas where competition venues have been built recently.

The year 1973 is generally considered as the birth year of mountain biking (MB) and the Mount Tamalpais in Marin County, California, as place of birth. From a historic point, the concept of off-road bicycles was applied already in the expedition of Buffalo Soldiers from Missoula, Montana, to Yellowstone and back in August 1896. "Cyclo-cross" is another early example for off-road cycling introduced in the early 1940s by road racing cyclists to keep fit during the winter. Later on this sport became its own rights and the first world championship was held in the 1950s. Between 1951 and 1956, the French Velo Cross Club Parisien (VCCP) members developed a sport in the outskirts of Paris that was very similar to the today's mountain biking. In the United Kingdom, in 1955, cyclists founded the Roughstuff Fellowship and in 1966 D. Gwynn invented a bicycle for off-road terrain which he named "mountain bicycle." Geoff Apps, an English motorbike rider, started to experiment with off-road bicycle designs in 1968. By 1979 he had developed lightweight metal frameworks that were customized and perfectly suited in combination with thick tires for muddy off-road cycling.

The so-called Schwinn cruisers, a sturdy and heavy bike type with thick balloon tires from the 1930s and 1940s were used and modified by a group of bikers like Gary Fisher, Joe Breeze, and Charles Kelly to speed down the dirt roads of Mount Tamalpais in Marin County, California, in the 1970s. Due to its geometry, the "Schwinn excelsior" was the frame of choice. Their modification by using motocross or BMX style frame parts created the so-called klunkers.

In the USA the development of bikes for off-road purposes started in the late 1970s and was pushed by several bikers such as Joe Breeze, Gary Fisher, Charlie Kelly, and Tom Ritchey. Joe Breeze is credited with the introduction of the first mountain bike in 1978. Tom Ritchey, Charlie Kelly, and Gary Fisher founded the partnership "MountainBikes" introducing the first original mountain bikes. They were basically road bikes with wider frame and fork to allow thicker tires. Tom Ritchey was credited with the development of

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Fig. 12.1 Extreme mountain biking can be performed at incredible places, especially in mountainous areas (Photo courtesy of Manfred Stromberger)

the first mountain bike frame with transverse-mounted handlebar. The company "Mountain Bikes" pioneered with the first mass production of mountain bikes, followed by Tom Ritchey, who dissolved later from the company, and specialized.

The first mountain bike competitions were started in 1976 at Mount Tamalpais as well. These competitions were the impulse for a whole series of technical modifications, which was the beginning of the development of the today's mountain bike technical features. Gary Fisher was the first biker who introduced a gear shift fixed to the handlebar, which made it much easier for the biker changing gears in stand-up position during competition. However, the exact technical development cannot be traced back due to a lack of documentation. Since the beginning many subdisciplines have been introduced, and the corresponding technical development was always orientated to the appropriate need of bike discipline.

In the last decade extreme mountain biking (Fig. 12.1) became very popular, and nowadays at nearly every undulating landscape with favorable tracks or off-road trails, bikers can be admired doing long uphill tracks. It almost looks like mountain biking became one of the most popular summer sports in mountainous areas.

The idea of practicing mountain biking during the summer season in areas with sufficient undulating landscapes with favorable trail conditions seemed to be a natural progression. However, going up- and downhill in some matter may not be enough. It is in our nature to develop and adapt competences. Making use of the same principle of transforming strength and energy into a propelling force, downhill mountain bikers are able to reach high velocities (Fig. 12.2). Freeriders or dirt jumpers perform spectacular jumps combined with BMX style tricks due to the vertical lift created by artificial or natural redoubts (Fig. 12.3).

So far many subdisciplines with varying technical features have been introduced. Basically they differ according to meet their sporty demands. Nevertheless the frame's center of gravity or weight stays in focus. In the following section, each subdiscipline and its equipment are going to be introduced.

12.2 Mountain Biking

12.2.1 Disciplines

12.2.1.1 Cross-Country (XC)

Cross-country (XC) is one of the most popular mountain bike disciplines, and nowadays it is already an official Olympic discipline. Compared to a Formula 1 race in cross-country (XC), a round

Fig. 12.2 A compact and low frame with a low bottom-bracket height gives the downhill biker the best possible traction and an easy handling while riding at high velocities (Photo courtesy of Felix Weilbach)

Fig. 12.3 High velocity enables the athlete performing breath-taking jumps and tricks (Photo courtesy of Felix Jäger)

course is established which has to be completed multiple times by the athletes. The race is over either when a certain number of rounds are completed or when a certain time interval expired. The racetrack is usually between 3 and 9 km long and has to include the following terrain features:

- Amount of brick floors or asphalted streets less than 15 %
- Forest and country tracks
- Meadow trails
- Multiple gradients and descents

12.2.1.2 Downhill Mountain Biking (DMB)

Downhill mountain biking (DMB) is the general sense of to racing-oriented downhill riding. This sport is performed in the summer all over the world, especially in mountainous areas. It involves high velocities that runs up to 70 km/h, bolds maneuvers, turns, and jumps. In combination with hard and rocky underground spiked with natural or wooden obstacles, the difficulty consists of finding the best line between the highest speed and lowest danger of accident.

12.2.1.3 Freeride (FR)

Freeride (FR) includes elements from DMB however without fenced-off racing tracks and race clock. It is a “do anything” sports category of mountain biking. It combines breath-taking stunts with BMX style tricks and riding trails. The athletes require more technical skills and body control than XC athletes. “Big mountain freeride” is another and much more extremer style than FR. This sport was shaped through the biggest drops and most dangerous runs on off-road terrain with often 40° of slope. Events such as Red Bull Rampage in Utah, USA, made this style of FR very popular.

12.2.1.4 All-Mountain/Enduro (AM)

The all-mountain (AM) category resembles the traditional mountain biking the most. All athletes have to overcome a track with climbs and descents on a variety of terrain in the shortest time as possible. While traditionally called all-mountain riding, this style has been adopted to the Enduro World Series. There are three types of Enduro riding. The first is “Big Mountain” Enduro and very similar to DMB but much longer. A defined and timed course with incorporated climbing sections has to been overcome and sometimes it takes the whole day to complete the course. The second “Gravity” Enduro style has the same amount of climbing and downhill sections, but the climbing sections are not timed. However, there is a maximum of time in which an athlete has to reach the top of the climb. The third “Super D” Enduro style is similar to XC race with climbs followed by descent sections on a defined track.

12.2.1.5 Four-Cross/Dual Slalom (4X)

In both sports the athletes compete in slaloms either in short slalom tracks as in four-cross (4X) or on separated tracks as in dual slaloms against other athletes.

12.2.1.6 Dirt Jumping (DJ)

As its name implies, the idea behind this sport is to ride the bike over a shaped hill of soil or mud and to become airborne after riding over the “takeoff” and to perform rotations and tricks while aiming a clean “landing.”

12.2.2 Equipment

To practice each subtype of EMB, basic and individual equipment is needed and has to be adjusted according to the athlete’s weight, skill level, and different track and weather conditions.

12.2.2.1 Bike Technique

Typical characteristics of a mountain bike are wide tires with 559 mm rim diameter. Derailleur gears are also typical with 21–30 gears being frequently employed. Common translations are 44/32/22 in the front with triple chainrings and 11–32, 34, or 36 at the rear with eight, nine, or ten sprockets. In downhill and dirt bikes, only one chainring with chain guide is used.

Mountain bikes have a relatively small frame with steeply sloping top tube. Usually large pipe diameters are used especially in aluminum frames. Aluminum was the material of choice used to build frames, but increasingly carbon fiber reinforced plastics are employed. They are much lighter but also vulnerable to breach. Already a stone impact or scratches can damage fibers and weaken the structure of the frame after a fall. Frames made of titanium are also an alternative option. They are particularly comfortable and corrosion safe but also very expensive. Mountain bikes with frames made of steel or titanium are found almost exclusively in the high-price sector.

Cantilever brakes (V-brakes and hydraulic rim brakes) were frequently installed on mountain bike frames. Today’s bikes are often equipped with disk brakes. Shock-absorbing forks are now standard equipment as well. In addition to the shock-absorbing front fork, rear suspension in mountain bikes is also increasingly used. In contrast to full suspension bikes (“fully”), bikes with rigid rear are called hardtail.

12.2.2.2 Suspension Systems

At the beginning of this sport, suspension systems were based on elastomers. Later on, they were replaced by steel suspension and air suspension. Steel suspension systems are usually preferred in downhill bikes in which the material is exposed to high-energy loaded forces and the need of high reliability is required. Air suspensions are primarily used in cross-country bikes due to the importance of the bicycle's weight.

12.2.2.3 Front Suspension

The so-called forks are the suspension of the front wheel basically consisting of two tubes on each side in which one contains the suspension and the other one the dumping. Oil can usually be found as damping medium in suspension forks and air or steel as spring. Forks with air spring have the advantage that they are usually mild and the spring hardness can be adjusted via a valve. The steel spring has a linear force-way curve and responds more easily because it has less friction. There are numerous suspension fork systems that can be manually adjusted.

12.2.2.4 Wire Tires

This type of tire is the most prevalent tire used in bike sports. At the bottom of the tire flank, a solid core is incorporated, which forms a ridge with the surrounding material. Different types of wire tires exist and, for example, tubeless tires are widely used in downhill mountain biking. The advantage is the ability to drive it at low pressure without the risk of damage to the tube.

12.2.2.5 Tube Tires

In tube tires the outer tire is sewn together building a closed shell in which the tube lies inside. The advantage of this design is the low weight and usually a very low rolling resistance. Broken tires can be fixed by replacing the tube, but the costs are high and therefore they are only used in professional sports.

12.2.2.6 Solid Rubber Tires

Solid rubber tires are mounted on same rims as wire tires. Their advantage is the high puncture resistance, and their disadvantage is their high rolling resistance and extreme weight.

12.2.2.7 Air Pressure

The optimum air pressure in tires depends on different aspects but also by the personal taste: In mountain bikes, downhill or cross-country bike traction and suspension have priority. The pressure in all terrain is between 1.8–2.5 and 2–4 bars for tubeless tires and 7–13 bars for tube tires. Each athlete adjusts the pressure depending on the ground and his weight. The individual setting has advantages and disadvantages such as lower pressure for higher traction in rough terrain but less stability in curves and higher pressure for less rolling resistance on asphalted streets. In combination with every bike system, every rider can set the suspension individually dependent on route conditions and athlete's weight including pitch of spring, compression, and rebound damping.

12.2.3 Subdiscipline-Specific Equipment

12.2.3.1 All-Mountain (AM)

The advantage of fully suspended AM bikes is the range of application from simple tours on plain landscapes up to alpine crossing tracks. More focus lies on reliability, comfort, and reserves in range of spring and less on the weight. The seating position is less stretched than a cross-country bike but still not as upright as compared to an Enduro bike.

The variability and the adjustment possibilities are essential for an AM bike. The range of spring is 120–160 mm. In some systems it can be entirely blocked for better uphill riding. On the other hand, some AM bikes offer the adjustment of the rear shock system. The weight starts at about 10 kg and goes up to 14 kg depending on the model. Wider and more profiled tires are used in AM compared to cross-country. AM bikes need to meet different requirements during the course of a race.

12.2.3.2 Downhill Mountain Biking (DMB)

Downhill bike frames mostly weight between 15 and 20 kg and are much heavier compared to all-mountain or cross-country bikes. Depending on the height of the athletes, different frame sizes are used ranging from extra small to extra large. The main keys and differences to other bikes are the center of gravity and front and rear suspension. Their construction allows the absorption of the bumpiness of the area leading to independence of driving and brake forces. The wheels

Fig. 12.4 *1* top tube (length, 560–620 mm); *2* seat tube (430–480 mm); *3* front suspension; *4* rear suspension; *5* upper linkages consisting of two wheel articulations which act in one axis; *6* regarding the suspension centers of rotation on each side absorb the bumpiness of the area additionally

have reinforced rims and spokes, four flask brakes, and a lower bottom-bracket height (ground to bottom-bracket height, 355 mm). The special construction of such downhill bikes with low frame, high suspension, and wide wheels offers easy handling and high traction (Fig. 12.4).

12.2.3.3 Cross-Country (XC)

Compared to DMB bikes, XC bikes are rather designed for unpaved roads than for heavy terrain. Both hardtail and full suspension bikes exist. Due to cost, durability, and weight, many drivers prefer hardtail bikes. Bike weights below 8 kg are achievable but costly. Their range of spring is between 80 and 100 mm and disk brakes are the state of the art.

12.2.3.4 Enduro

Enduro bikes have full suspension systems and in comparison to XC and mountain bikes, their range of spring is between 150 and 180 mm. Due to their different frame geometry, their weight lies between 12 and 16 kg and fitted with an adjustable landing gear, broader and more profiled tires. The handlebar is often cranked and the position is upright. The difference to FR bikes is that Enduros are much more crossing tour suitable. The large range of spring provides enough cushion in downhill parts or in drops and jumps – with lowered fork the Enduro is pleasant to ride uphill.

12.2.3.5 Freeride (FR)

FR bikes are very similar to DMB bikes – designed for use in heavy, steep terrain and fully suspended with a long range of spring from 150 to 200 mm. In contrast to the DMB, they are designed not only to departures. Due to modern suspension systems, it is possible with such heavy 20 kg bikes to go uphill as well. They prevent seesawing during pedaling and climbing sections are possible to attack.

12.2.3.6 Dirt Jumping (DJ)

Dirt bikes are sturdy mountain bikes with small, agile frames but also fitted with suspension leading to 65–100 mm deflection. The wheel size is not limited by 26 inches; also 24-inch wheels are often found. The weight stays in focus and kept mostly low in order to facilitate jumps. Also, the low weight favors rotations of the driver or of the bikes.

12.2.3.7 Four-Cross/Dual Slalom (4X)

4X bikes are pretty similar to dirt bikes. Mainly hardtails are used by the athletes and the frames are constructed slightly longer to maintain smooth running at high speeds.

12.3 Injury and Fatality Rates and Specific Types of Injury Related to the Sport

In recent years, extreme mountain biking has become a popular extreme sport drawing increased numbers of participants at both competitive and noncompetitive level. This sport involves high-velocity runs including jumps, turns, and various maneuvers. In combination with hard, rocky, and slippy underground, it leads to high risk of serious injuries. To defy these demands, the athletes use bikes, which provide the best possible traction and suspension in order to enable the athlete to perform its best run. Up until recently, little was known about the true risk, incidences, and causes of off-road biking injuries.

Pfeiffer was the first who started reporting about acute injuries in off-road bicycling among competitive and recreational cyclists [1]. In 1995 he published an overview stating that off-road bikers sustain more severe injuries. However, the reported risk for injury was still low ranging from 0.2 to 0.39 injury per ride for competitive venues compared to 0.30 % for recreational bikers. One year later a comparison between cross-country and downhill mountain races investigating injury rates and pattern was published by Kronisch et al. [2]. No significantly difference for injury rate in cross-country (0.49 %) and downhill mountain biking (0.51 %) races could be determined. However, while racing in a competition, 4.34 downhill mountain biking injuries per 100 h of exposure compared to 0.37 cross-country injuries were recorded ($p = 0.01$) indicating a higher risk for downhill mountain bikers. Most common injury types determined in cross-country vs. downhill mountain biking were abrasions (64 % vs. 40 %), followed by fractures (7 % vs. 15 %) and sprains (5 % vs. 10 %). The lower extremity was the most commonly injured body part for both disciplines (40 % vs. 30 %) followed by the upper extremity (38 % vs. 25 %). Bikers who fell over the handlebar exhibited a higher mean injury severity score compared to athletes who fell off to the side (3.0 vs. 1.3; $p = 0.01$) leading to a higher rate of emergency room visits (6/10 vs. 1/10; $p = 0.01$). Female competitors were more likely to be injured than men (5/6 vs. 5/14; $p = 0.05$). Nevertheless, most injuries were minor and the calculated risk of being injured was rather low. Interestingly, another report investigating acute traumatic injuries during off-road races reported similar results [3]. In 16 cases injuries were reported as severe by preventing the athlete to complete his run leading to an overall injury rate of 0.40 %. Together all 16 athletes had 44 injuries ranging from lacerations to fractures. However, abrasions were the most common injury type, followed by lacerations, contusions, fractures, and concussions. The mean injury severity score was 3.0 of which 81.2 % were sustained by bikers going downhill. Due to such investigations, first thoughts have been expressed suggesting that the risk factor for acute traumatic injury varies with the type of competition involved.

The first prospective report in the literature regarding injury types and rates among extreme mountain biking was published in 2001 by Jeys et al. [4]. They reported a total of 133 injuries in 84 patients ranging from one to six injuries per patient over 1 year. The injury type ranged from minor soft tissue lacerations to life-threatening injuries. The most common injury was the fracture of the clavicle (13 %), followed by other shoulder girdle injuries (12 %) and fracture of the distal radius (11 %). Moreover, they reported six patients with open or closed fractures of the femur and tibia. Even one patient sustained a dislocated C2/3 fracture with neurological deficit requiring operative stabilization. The second most severe injury in this series was a patient requiring nephrectomy to control hemorrhaging. However, most of the injuries were minor.

Similarly severe injuries have been reported retrospectively by Apsingi et al. [5] including acute cervical spine injuries in three cases. In all three cases, a neurological examination revealed either an incomplete or complete tetraplegia due to subluxation of a vertebral body of the neck or spinal cord compression.

In 2005, Arnold et al. [6] presented a questionnaire-based study analyzing causes and pattern of different subdisciplines such as XC, DMB, and mountain biking. In professional bikers, the most injured region was the shoulder including the clavicle and AC joint (25 %), followed by the knee (21 %) and elbow and forearm and hand (18 %). In less experienced bikers, the shoulder girdle was the most frequently injured body part as well (15 %). The head and neck

(11 %), likewise the wrist and hand (11 %), were the second most injured regions followed by the knee (7 %). Overall they reported 6.8 injuries for men and 12.0 injuries for women per 1000 h of exposure; most of them were minor.

An interesting retrospective study was published in 2007 by Himmelreich et al. [7] in which injury rate and incidence among competitive and recreational XC and DMB athletes were investigated. A total of 80 % of the World Cup athletes reported at least one severe injury compared to recreational riders of whom only 50 % sustained one. They showed that DMB athletes (1.08 injuries per 1000 h of exposure) had more than a double times higher injury rate compared to XC athletes (0.39/1000 h). Interestingly, for competitive and recreational bikers, injuries of the lower (47 vs. 35 %) and upper extremity (40 vs. 41 %) showed similar prevalence. Abrasions and lacerations were the most common injury for recreational athletes, while competitive bikers had a significant higher fracture rate ($p<0.01$). Forty head injuries were detected during the World Cup series. However, participation in the World Cup did not increase the injury rate. Only a higher injury risk for DMB athletes could be determined.

Gaulrapp et al. [8] performed a retrospective questionnaire-based study assessing risk factors, types, and body site of injuries occurring in a population of 3873 EMB athletes. Overall 3473 bikers, of whom 36 % participated in competitions, reported 8133 single injuries. Most of the injuries were minor resulting in a total injury risk rate of 0.6 % per year and one injury per 1000 h of biking. Personal factors, such as excessive speed, riding errors, or poor judgment, were the most common risk factors besides slippery road surface. While abrasions and contusions were the most injury types leading to a total of 75 % of all reported injuries, 10 % severe injuries were reported requiring a prolonged hospital stay.

In a recent study performed at the authors' institution, 249 downhill athletes from Germany, Luxembourg, Switzerland, and Austria were prospectively surveyed over one summer season ranging from April until September to determine injury rate, cause, and patterns [9]. A total of 494 injuries during 29.401 downhill hours occurred; of these 65 % were mild, 22 % moderate, and 13 % severe. The calculated injury rate was 16.8 injuries per 1000 h of downhill mountain biking. This is distinctly higher than the reported injury rate for cross-country mountain biking above. Nevertheless, no catastrophic injury was reported. Of all athletes 80 % reported multiple injuries over the course of the season, and in 47 % of all cases, multiple body sites were affected.

The most commonly injured body part while Downhill Mountain biking was the lower leg (27 %). Second was the forearm with 25 %, followed by the knee with 21 % (Table 12.1).

The most commonly reported types of injury were abrasions (64 %), contusions (57 %), and distorsions (15 %; Table 12.2).

As further analyzed most common lower leg injuries were abrasions (81 %) and contusions (55 %). In forearm injuries abrasions (93 %) and contusions (60 %) were predominant as well. Overall 32 fractures were reported in this study of which six were clavicle fractures. Five bikers reported rib fractures of which two cases were

Table 12.1 Affected body region in case of injury ($n=494$)

Anatomic region	*n*
Calf	134
Forearm	121
Knee	103
Elbow	97
Hand	93
Shoulder	86
Thigh	85
Wrist	64
Hip	63
Ankle	43
Head/face	38
Ribs	36
Upper arm	33
Pelvis	28
Neck/cervical spine	21
Foot	19
Upper back	17
Lower back	17
Clavicula	17
Abdomen	13
Others	21

Table 12.2 Sustained injuries in case of accident ($n=494$)

Injury type	*n*
Abrasion	316
Contusion	279
Distortion	72
Laceration	62
Strained muscle	45
Fracture	32
Concussion	23
Ligament strain	23
Joint dislocation	15
Joint inflammation	7
Ligament rupture	4
Torn muscle fiber	2
Others	23

multiple rib fractures, followed by three finger fractures as the third most common fracture type. The most severe injury sustained by an athlete was a concussion with an intracranial hemorrhage in combination with multiple rib fractures (rib III-XI) and fractures of two fingers.

Due to the character of the sport, the runs are mostly performed over the whole day. Most injuries occurred at the middle of the day (58 %), whereas the rest was distributed evenly between the beginning (21 %) and the end (20 %) of the day. Most accidents occurred in curves (43 %), followed by accidents during jumps (32 %) likewise sloping terrain (32 %). In 63 % of the injury events, the athletes lost control on soil, followed by stones (45 %) and roots on the ground (33 %). Following a jump, most frequent landing zone terrain leading to an accident was soil (66 %), stone (44 %), or roots (24 %). Thirty-one percent of the injury events were associated with greater irregularities, excessive roots, and slippy underground considered as rather poor trail conditions. However, 30 % of the injuries were reported despite rather good trail conditions (small irregularities, scattered roots, and no slippy underground). Conversely, at the time of injury, 51 % of the athletes reported good weather conditions. Multiple causes were reported as injury circumstances, of which the most common were riding errors (72 %), poor trail conditions (31 %), and unforeseen trail obstacles (16 %; Table 12.3).

Table 12.3 Causes of accidents ($n=494$)

Cause	No.
Driving error	355
Trail conditions	155
Route obstacles	81
Overfatigue	50
Weather	40
Wrong choice of materials	38
Poor sight	18
Technical failure	16
Collision with other driver	8

Multiple causes possible

We determined a significantly higher injury rate of 17.9 (per 1000 h of exposure) for experts compared to professional riders (13.0 injuries per 1000 h of exposure; OR 1.34; 95 % CI, 1.02–1.75; $p=0.03$) assuming that the injury risk tends to become less for DMB athletes gaining more experience by practicing higher jumps with higher velocities. Moreover, a significantly higher rate of injury was reported during competition (20.0 injuries per 1000 h of exposure) than during practice (13.0 injuries per 1000 h of exposure; OR 1.53; 95 % CI, 1.16–2.01). However, no significant differences have been determined in the rate of mild (OR 1.26; 95 % CI, 0.90–1.75; $p=0.17$) versus severe injuries (OR 1.40; 95 % CI, 1.16–2.01; $p=0.01$). In the course of this study, only a few head and neck injuries have been recorded.

12.4 Common Treatments for Each Sport and Relevant Rehabilitation

Most injuries in extreme mountain biking are minor or moderate, but serious injuries, including internal organ damage and bleeding, are also possible (Fig. 12.5).

Contrast-enhanced computed tomography (CT) showed a laceration of the upper pole of the right kidney (point of arrow), associated with perirenal hematoma with a maximum thickness of 24 mm in the axial scans, with signs of extravasation of contrast material within the hematoma (arrow).

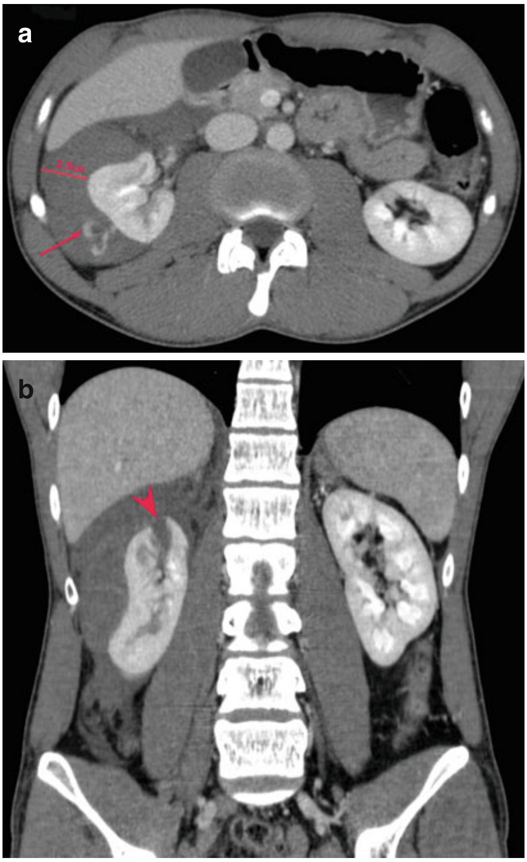

Fig. 12.5 (**a**, **b**) Case of a 25-year-old mountain biker who suffered renal damage and perirenal hematoma following a fall during a downhill session (Courtesy of Dr. Feletti, own case series)

Since the patient was hemodynamically stable, the laboratory parameters showed no significant alterations, and signs of hematuria were absent, and a conservative treatment approach was adopted, involving bed rest, ice packs, and a strict monitoring of the patient's clinical status and laboratory values, with an initial reassessment by CT after 6–8 h.

At CT follow-up, the hematoma showed no significant increase in size, and the signs of active bleeding had disappeared. Clinical and laboratory parameters were stable.

The patient was successfully treated using an ongoing conservative approach, involving the monitoring of clinical status and laboratory parameters, together with periodic follow-up ultrasounds (courtesy of Francesco Feletti; own case series).

In the two largest prospectively observed studies reported in the literature regarding off-road cycling and downhill mountain biking injuries, only 8–13 % were severe without any catastrophic injury documented. Even the retrospective surveys had similar results. However, due to the recall bias, such surveys are not comparable. The prospective survey of downhill mountain biking published by the authors is the only study, which tells us an accurate relationship between mild and moderate injuries. In this survey the relationship was 3:1.

In general injury treatment follows general guidelines of trauma care and sports medicine. Obviously, extreme mountain bikers suffer more frequently from mild injuries such as skin lesions. Abrasions and lacerations are often soiled, and therefore, adequate quick primary wound care management regarding cleaning and disinfection represents an important aspect already as first-aid measurement. Conservative treatment using splints or joint ortheses is the treatment of choice for joint sprains, muscle sprains, and minor ligament injuries.

Fractures represent the main part of moderate injuries. The decision on surgical or nonsurgical treatment depends on several factors and must be made by the trauma surgeon individually.

Signs of concussion, loss of sensibility, and motoric function after a fall should be taken seriously resulting in an adequate transport of the patient to a trauma center.

Rehabilitation times are injury dependent and have to be assessed individually by the treating physician. An important aspect after long injury-related abstinence from sports represents the general physical condition and fitness. To gain full convalescence, not only injury-specific rehabilitation measures should be taken, but general fitness and physical training programs are also recommended.

12.5 Proposed Prevention Measures

Extreme mountain biking is considered to be an extreme sport and therefore potentially dangerous. Beginners without appropriate instruction should not attempt some subdisciplines especially downhill mountain biking. Basic riding skills are recommended as minimum competence levels before practicing in mountainous landscape. This includes all aspects of safe handling of bikes on street and off-road terrain concerning to be in control during uphill rough terrain, slippy underground while riding downhill, curves on the street or on off-road trails, vanquishing artificial trail obstacles, high-speed downhill sections, and landing unaided in the landing zone after a jump.

All extreme mountain bikers are required to respect general safety guidelines, as staying clear on the off-road trail or in the case of downhill mountain biking fenced-off trails. Weather conditions should always be taken in consideration. Particularly athletes of subdisciplines with downhill sections such as DMB, XC, or Enduro should use the right set of tires increasing the bike's traction under wet conditions. If riding off-road in unknown terrain, an accompanying experienced biker should be present.

An often-underestimated risk factor is the own assessment of riding skills. Depending on different biking venues or off-road trails, the athletes should always have information about the difficulty of the trails.

Certain prevention measures should be considered when performing EMB. Beginners should be introduced to this sport by a professional instructor or more advanced rider in order to be informed about the correct technique, usage of adequate equipment in different weather and trail conditions, and potential hazards to be aware of. Many extreme mountain bikers like to perform their sport on high-speed sections. Due to the higher speed, such trails convey an increased risk of injury. Even in known biking venues, it must be paid close attention that no unexpected obstacles are present on the trail, such as fallen trees or hikers. The use of safety equipment is of crucial importance. Athletes without helmets are at greater risk to sustain fatal head injuries leading to disability or death. Neck braces are often used, and in combination with full-face helmets, it should be part of every safety equipment while riding high-speed downhill sections. Body protection including gloves, safety glasses, protector jackets, shin guards, and back and wrist protectors should be worn accordingly to each subdiscipline. Both the spine and the back are at great risk of injury when trying high jumps or riding high speed on a hard and rough terrain. Of course, many other kinds of protectors that are available can be of benefit in case of an accident and should be considered. Further factors regarding the equipment should be taken into consideration. Every product has its limitations, which are depicted by the manufacturer's instructions and safety guidelines and have to be followed. A regular check and maintenance of the equipment are necessary to warrant its safety before riding. The development of more advanced devices is admittedly difficult but would increase the safety of the riders significantly, when functioning properly.

Finally, each subtype of EMB has to be considered an extreme sport. This means for all athletes practicing these sports, good physical condition is required including muscular strength, endurance, and mental fitness for competition as well as for practice. For untrained athletes a special physical preparation should be completed before the season. In order to reduce the risk of injury and to resist physical demands, the training should focus on endurance, strength, balance, and coordination.

All in all, it can be said that extreme mountain biking is becoming one of the most popular extreme sports in mountainous areas. Of course, as every extreme sport, it conveys a certain risk of injury. However, with the right instructions, equipment, and safety precautions, those risks can be diminished.

References

1. Pfeiffer RP, Kronisch RL. Off-road cycling injuries An overview. Sports Med. 1995;19(5):311–25.
2. Kronisch RL, Pfeiffer RP, Chow TK. Acute injuries in cross-country and downhill off-road bicycle racing. Med Sci Sports Exerc. 1996;28(11):1351–5.
3. Kronisch RL, Chow TK, Simon LM, Wong PF. Acute injuries in off-road bicycle racing. Am J Sports Med. 1996;24(1):88–93.
4. Jeys LM, Cribb G, Toms AD, Hay SM. Mountain biking injuries in rural England. Br J Sports Med. 2001;35(3):197–9.

5. Apsingi S, Dussa CU, Soni BM. Acute cervical spine injuries in mountain biking: a report of 3 cases. Am J Sports Med. 2006;34(3):487–9.
6. Arnold MP. Mountain biking. Cool way to enjoy nature with side effects. Orthopade. 2005;34(5):405–10.
7. Himmelreich H, Pralle H, Vogt L, Banzer W. Mountainbike injuries in world-cup and recreational athletes. Sportverletz Sportschaden. 2007;21(4):180–4.
8. Gaulrapp H, Weber A, Rosemeyer B. Injuries in mountain biking. Knee Surg Sports Traumatol Arthrosc. 2001;9(1):48–53.
9. Becker J, Runer A, Neunhauserer D, Frick N, Resch H, Moroder P. A prospective study of downhill mountain biking injuries. Br J Sports Med. 2013;47(7):458–62.

Ultramarathon Running: Medical Issues

13

Beat Knechtle

13.1 Ultramarathons

13.1.1 What Is an Ultramarathon?

An ultramarathon is defined as any sporting event involving running longer than the traditional marathon length of 42.195 km [1]. Therefore, the shortest ultramarathon is the 50-km ultramarathon. Ultramarathons can be held as distance-limited races in kilometers or miles and in time-limited races in hours or days [1].

13.1.2 Who Are Ultramarathoners?

In recent years, Hoffman systematically investigated sociodemographic characteristics of ultramarathoners [2, 3]. In a survey completed by 489 of 674 runners competing in two of the largest 161-km ultramarathons in North America, respondents had a mean age of 44.5 years and were generally men (80.2 %), were married (70.1 %), and had bachelor's (43.6 %) or graduate (37.2 %) degrees [2]. In the Ultrarunners Longitudinal Tracking (ULTRA) Study, Hoffman and Krishnan [3] interviewed a total of 1345 current and former ultramarathoners. Median age at the first ultramarathon was 36 years, and the median number of years of regular running before the first ultramarathon was seven [3]. The age at the first ultramarathon did not change across the past several decades, but there was evidence of an inverse relationship between the number of years of regular running before the first ultramarathon and the calendar year [3]. The active ultramarathoners had a previous year median running distance of 3347 km, which was minimally related to age but mostly related to their longest ultramarathon competition of the year [3].

13.1.3 Women in Ultramarathons

The share of women competing in ultramarathons was very low in the beginning of ultramarathon running. In 161-km ultramarathons held in the USA, the participation among women increased from virtually none in the late 1970s to nearly 20 % since 2004 [4]. Their percentage is now at ~20 % [4–6]. In two of the toughest ultramarathons in the world, women accounted on average for ~21.5 % in "Badwater Ultramarathon" and ~10.8 % in "Spartathlon" [5]. In most ultramarathons, the number of female finishers increased across years [5, 6]. For example, in the "Swiss Alpine Marathon" in Switzerland, women's participation increased from ~10 % in 1998 to ~16 % in 2011 [6]. In "Badwater Ultramarathon" and

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"Spartathlon," there was an increase in female participation in "Badwater Ultramarathon" from 18.4 to 19.1 % and in "Spartathlon" from 11.9 to 12.5 % [5]. The rather low female participation might have different reasons. A potential explanation might be motivation. Female ultramarathoners were task-oriented, internally motivated, health, and financially conscious individuals [7]. Men, however, trend rather to compete in order to beat a concurrent or to win a race.

13.1.4 Where Are Ultramarathons Held?

Ultramarathon races are offered all over the world. There are some of the most famous races such as the "Badwater Ultramarathon" (held in USA), the "Spartathlon" (held in Greece), and the "Marathon des Sables" (held in Morocco) just to name the best known [1]. Some of these races are held under extreme conditions such as extreme heat [8]. A problem of races held in heat is the fact that performance will be impaired [9, 10]. A very recent study showed that athletes would benefit from heat acclimation. Exposure to at least 2 h of exercise-heat stress on at least two occasions in the days may help in preventing exertional heat illnesses and optimizing performance outcomes in ultra-endurance runners in multistage ultramarathon competition in the heat [11].

13.1.5 Where Do Ultramarathoners Originate From?

It is well known that East-African athletes such as Kenyans and Ethiopians dominate the marathon events all over the world for decades [12, 13]. In ultramarathon running, however, athletes from other regions were dominating both participation and performance. For example, in 100-km ultramarathons, most of the finishers originated from Europe, in particular from France [14]. The number of finishers from Japan, Germany, Italy, Poland, and the United States of America increased exponentially between 1998 and 2011. For women, runners from Canada became slower while those from Italy became faster. For men, runners from Belgium, Canada, and Japan became slower. Between 1998 and 2011, the ten best race times were achieved by Japanese runners for both women with ~457 min and men with ~393 min [14]. In ultramarathons longer than the 100 km, athletes from other countries seemed to dominate participation and performance. Ultramarathoners competing in the world's most famous races "Badwater Ultramarathon" (USA) and "Spartathlon" (Greece) originated from different regions [15]. In "Badwater Ultramarathon," most of the finishes were achieved by athletes originating from the USA, followed by athletes from Germany and Great Britain. In "Spartathlon," however, the highest number of finishes was obtained by athletes from Japan, followed by athletes from Germany and France. Regarding performance, however, athletes from other countries were dominating. In "Badwater Ultramarathon," women from the USA were the fastest, followed by women from Canada. For men, the fastest finishes were achieved by competitors from the USA, followed by athletes from Mexico and Canada. In "Spartathlon," the fastest female finishes were obtained by women from Japan, followed by women from Germany and the USA. In men, the fastest finishes were achieved by runners from Greece, followed by athletes from Japan and Germany [15]. In the "Marathon des Sables" held in the Moroccan desert, local athletes seemed to dominate [8]. In men, Moroccans won nine of ten competitions, and one edition was won by a Jordanian athlete. In women, however, eight races were won by Europeans (i.e., France five, Luxembourg two, and Spain one, respectively), and two events were won by Moroccan runners [8].

13.2 Are Ultramarathoners Different to Marathoners?

Several studies compared recreational marathoners to recreational ultramarathoners regarding anthropometric [16, 17] and training [16–19] characteristics. Most probably, ultra-runners start with a marathon before completing the first ultramarathon. In ultramarathoners, the number of previously completed marathons is significantly higher than the number of completed marathons in marathoners. However, recreational marathoners have a faster personal best marathon time than ultramarathoners. Successful ultramarathoners have ~8 years of experience in ultra-running. Ultramarathoners complete more running kilometers in training than marathoners do, but they run more slowly during training than marathoners [18, 19].

Marathoners show difference in anthropometry compared to ultramarathoners. When marathoners were compared to 100-km ultramarathoners [16], marathoners had a significantly lower calf circumference and a significantly thicker skinfold at pectoral, axillary, and suprailiacal sites compared to ultramarathoners. When marathoners were compared to 24-h ultramarathoners [17], ultramarathoners were older, had a lower circumference at both the upper arm and thigh, and a lower skinfold thickness at the pectoral, axillary, and suprailiacal sites compared to the marathoners.

Marathoners show also differences in training compared to ultramarathoners. Marathoners rather rely on a high running speed during training [16], whereas ultramarathoners rely on a high running volume during training [16, 19]. When marathoners were compared to 100-km ultramarathoners [16], marathoners completed fewer hours and fewer kilometers during the week, but they were running faster during training than ultramarathoners. When marathoners were compared to 24-h ultramarathoners, the ultramarathoners were running for more hours per week and completed more kilometers during training, but were running slower than the marathoners [17]. An interesting recent finding was that ultramarathoners have a greater pain tolerance than controls [20]. This fact might enable ultra-runners to endurance longer under different circumstances than others.

13.3 Predictor Variables for Successful Ultramarathon Running

In recent years, several studies tried to find the most important predictor variables for a successful outcome in ultramarathon running. Among these variables, the most important were age [16, 21], anthropometric characteristics such as body fat [16, 19], body mass index [22] and limb circumferences [23], training characteristics such as running speed [16, 19, 21] and training volume [16, 19, 21], and previous experience [24, 25].

Regarding anthropometric characteristics, leg skinfold thickness – which was highly predictive of short-distance runners [26] – was only predictive in bivariate analyses, but not in multivariate analyses, with ultramarathon running performance [24, 27]. In ultramarathoners, body mass index and body fat seemed to be more important anthropometric characteristics [22, 28]. In 161-km ultramarathoners, lower values of body mass index were associated with faster race times [22]. Body fat is also an important anthropometric predictor variable. In 161-km ultramarathon running, faster men have lower percent body fat values than slower men, and finishers have lower percent body fat than non-finishers [28].

When different characteristics such as skeletal muscle mass, body fat and training characteristics were investigated in multivariate analyses, and body fat and training characteristics were associated with running times in ultramarathoners [19]. For 100-km ultramarathoners, weekly running kilometers and average speed during training were negatively related to race time and the sum of skinfolds was positively related to race time [25]. Apart from anthropometric and training characteristics, age seems also to be an important predictor variable for ultramarathon performance. In 100-km ultramarathoners, age, body mass, and percent body fat were positively related to race times and weekly running kilometers were negatively related to race times [16].

Previous experience seems, however, to be the most important predictor variable in ultramarathon performance [22, 24, 29]. For example, personal best marathon time was a predictor variable in mountain ultramarathoners [22]. In 24-h ultramarathoners, anthropometry and training volume seemed not to have a major effect on race performance [24]. However, a fast personal best marathon time seemed to have the only positive association with race performance [24]. To achieve a maximum of kilometers in a 24-h ultramarathon, ultra-runners should have a personal best marathon time of ~3 h 20 min and complete a long training run of ~60 km before the race, whereas anthropometric characteristics such as low body fat or low skinfold thicknesses showed no association with performance [29].

13.3.1 Performance in Women and Men and Sex Difference in Performance

Generally, women compete slower than men in ultramarathon running [6, 30, 31]. Coast et al. [31] compared the world best running performances for race distances from 100 m to 200 km. The running speeds were different between women and men with the average difference being 12.4 % faster for men. There was a significant slope to the speed difference across distances where longer distances were associated with greater differences [31]. In 24-h ultramarathons held between 1977 and 2012, the sex differences were ~5 % for all women and men, ~13 % for the annual fastest finishers, ~13 % for the top ten, and ~12 % for the top 100 finishers [30].

However, women were able to reduce the sex gap in recent years [6, 30, 32]. For example, in 24-h ultramarathons, the sex differences decreased for the annual fastest to ~17 %, for the annual ten fastest to ~11 %, and for the annual 100 fastest to ~14 % [30]. Across years, female and male ultramarathoners improved performance [6, 32]. In 100-mile ultramarathons, the fastest women and men improved their race time by ~14 % across the 1998–2011 period [32].

13.3.2 The Age of Peak Ultramarathon Performance

The age of peak ultramarathon performance and a potential change in the age of peak performance have been intensively investigated in very recent years [5, 6, 30, 32–36]. Generally, the best ultramarathon performance is achieved at higher ages than the best marathon performance. The fastest marathoners achieved their best times at the age of ~29.8 years for women and ~28.9 years for men [37]. In 100-km ultramarathon running, the best race times were observed between 30 and 49 years for men and between 30 and 54 years for women [34]. In 161-km ultramarathoners, the fastest times were achieved by athletes ranked in the 30–39-year age group for men and the 40–49-year age group for women [38].

Generally, women achieved the best ultramarathon performance at about the same age like men [30, 32]. For 100-km ultramarathoners, the age of the fastest female and male finishers remained unchanged at ~35 years between 1960 and 2012 [33]. In 24-h ultramarathoners, the best performances were achieved at ~40–42 years [35].

In some instances, the age of the fastest finishers increased across years [6]; in other instances, it remained unchanged [30, 32] or it even decreased [5]. For example, in the annual fastest male 24-h ultramarathoners, the age of peak running speed increased from 23 years (1977) to 53 years (2012) [30]. There seemed to be a trend that the fastest finishers were older in the very long ultramarathon distances [30, 32]. In 100-mile ultramarathoners, the mean ages of the annual top ten fastest runners were ~39 years for women and ~37 years for men [32]. In 24-h ultramarathoners, the ages of peak running speed were unchanged at ~41 and ~44 years for the annual ten and the annual 100 fastest men, respectively. For women, the ages of the annual fastest, the annual ten fastest, and the annual 100 fastest remained unchanged at ~43 years, respectively [30]. In "Badwater Ultramarathon" and "Spartathlon" as two of the toughest ultramarathons in the world, the fastest race times were achieved by athletes at the age of ~40–42 years [36].

Generally, the number of master ultramarathoners increased and their performance improved in recent years [39, 40]. For example, in the "Swiss Alpine Marathon," the number of women older than 30 years and men older than 40 years increased and performance improved in women aged 40–44 years [40]. In the "Marathon des Sables," the number of finishers of master runners older than 40 years increased for both sexes and men aged 35–44 years improved running speed [39]. A potential explanation for the rather high age of ultramarathoners could be the finding that the median age at the first ultramarathon was 36 years in the study of Hoffman and Krishnan [3] when investigating 1345 current and former ultramarathoners.

13.4 Physiology of Ultramarathon Running

13.4.1 Energetic Demands During Ultramarathon Running

Successful completion of an ultramarathon such as the 161-km "Western States Endurance Run" is related to large consumption rates of fuel, fluid, and sodium [41]. During ultramarathon running, the most important energy source is carbohydrates [42–44]. In 100-km ultramarathoners, 88.6 % derived from carbohydrate, 6.7 % from fat, and 4.7 % from protein [44]. In one ultramarathoner completing a 1005-km race over 9 days, the nutrient analysis showed an average daily energy intake of 25,000 kJ with 62 % from carbohydrate, 27 % from fat, and 11 % from protein. Carbohydrate intake was estimated to be 16.8 g/kg/day and protein intake was estimated to be 2.9 g/kg/day [43].

Generally, ultramarathoners are not able to meet their energetic demands during a race [45, 46], and a partially considerable energy deficit results [45, 47, 48]. The insufficient energy intake in ultra-endurance athletes is also associated with a low antioxidant vitamin intake [46]. The large energy deficit is caused by inadequate energy intake, possibly due to suppressed appetite and gastrointestinal problems [45]. Ultramarathoners often suffer from problems with digestion [49] and gastrointestinal bleeding after an ultramarathon is not uncommon [50]. It has been shown that lower gastrointestinal symptoms correlate with gastrointestinal bleeding [50]. In a mountain ultramarathon, 43 percent of all subjects complained of gastrointestinal distress during the race [49]. A potential reason for these problems could be that exercise has been found to alter esophageal motility [51]. However, also prerace experience could be an explanation. Runners with gastrointestinal distress tended to complete fewer training miles and to do shorter training runs [52]. The result of the energy deficit is a decrease in body mass where both lean body mass (skeletal muscle mass) and fat mass will be reduced [53, 54].

13.4.2 Fluid and Electrolyte Metabolism During Ultra-Running

Ultramarathoners need to consume large amounts of fluids to prevent dehydration during running. During ultramarathon running, the largest decreases in body mass occur in the first hours of the race [55]. Large fluid intakes might, however, lead to an increased risk for exercise-associated hyponatremia, defined as plasma sodium concentration $[Na^+]$ <135 mmol/l. Several cases of hyponatremia, with symptoms including altered mentation, seizures, and pulmonary edema, have been reported in endurance athletes over the last few years. This condition has been observed most frequently in individuals participating in ultra-distance events but has also been reported in marathon runners. Excessive water intake has been identified as a common etiological factor [56].

However, there seemed to be no need to consume excessive amounts of fluid in ultramarathon running [57]. Generally, ultramarathoners seemed not to overdrink [58] and no fluid overload should occur during an ultramarathon [59]. In a 100-km ultramarathon, faster runners drank more fluid than slower runners and faster runners lost more body mass than slower runners. Additionally, runners lost more body mass when they drank less fluid [57]. Faster running speeds were associated with larger body mass losses. Therefore, athletes who drink less during ultramarathon running may profit from body mass loss and complete the race faster [57]. Also in a 160-km ultramarathon, greater loss in body mass during the race was not associated with impaired performance but was rather an aspect of superior performance [60].

13.5 Medical Disturbances Related to Ultramarathons

13.5.1 Exercise-Associated Hyponatremia in Ultramarathon Running

Exercise-associated hyponatremia is a rather frequently found electrolyte disorder in ultramarathoners [11, 61–63] where high ambient temperatures might be of high importance [11, 64]. In a five-stage 225-km multistage ultramarathon where athletes competed at temperatures of up to 40 °C, the prevalence of exercise-associated hyponatremia amounted to 42 % [11]. In the 2008 "Rio Del Lago 100-Mile Endurance Run" in Granite Bay, California, the prevalence of exercise-associated hyponatremia was at 51.2 % [64].

Exercise-associated hyponatremia is relatively uncommon in temperate climates [65–69]. In a seven-stage 350-km multistage mountain ultramarathon at moderate to low temperatures, the prevalence of exercise-associated hyponatremia was at 8 % [66]. In a 100-km ultramarathon [67, 68] and a 24-h run [69] held at moderate to low temperatures, no cases of exercise-associated hyponatremia were recorded.

The country where the ultramarathon is held seemed to be of importance. In races held in the USA, the prevalence of exercise-associated hyponatremia was higher than in races held in Europe. In the 2009 edition of the "Western States Endurance Run," the prevalence of EAH was 30 % [61]. In ultramarathons held in Switzerland, Europe, the prevalence of exercise-associated hyponatremia was between 0 and 8 % [66, 67, 69]. Also in ultramarathoners competing in the Czech Republic, Europe, the prevalence of exercise-associated hyponatremia was low [70].

An increased fluid intake during ultramarathon running might also have negative effects on the feet since recent studies showed an association between fluid intake and limb swellings [71, 72]. Fluid intake was related to the changes in limb volumes, where athletes with an increased fluid intake developed an increase in limb volumes [71]. An increase in feet volume after a 100-km ultramarathon was due to an increased fluid intake [72].

13.5.2 Pathophysiological Effects of Ultramarathon Running

Running an ultramarathon may lead to other disturbances apart from exercise-associated hyponatremia. Ultramarathon running is associated with a wide range of significant changes in hematological parameters, several of which are injury related. A single bout of strenuous running exercise results in perturbations to numerous biomarkers, and the magnitude of changes to biomarkers is proportional to the severity of the running bout [73]. Ultramarathon running can produce changes to biomarkers that are normally associated with pathology of the muscles, liver, and heart [74–76]. However, also markers of the inflammatory response such as C-reactive protein [77–79] and IL-6 [77, 79, 80] become elevated. Examples for biomarkers of pathology of muscles, liver, and heart are cardiac troponins, plasma volume, myoglobin, leucocytes, sodium, chloride, urea, alkaline phosphatase, gamma-glutamyl transferase, alanine aminotransferase, aspartate aminotransferase, lactate dehydrogenase, creatine kinase, bilirubin, total protein, albumin, glucose, calcium, and phosphate [73–76, 80–82]. A number of variables remain within normal limits despite severe physical stress [80]. These changes are transient, and full recovery generally occurs within days and without any apparent long-term adverse consequences [73, 76]. For example, a 48-h ultramarathon caused hypocapnic alkalosis with slight hyperkalemia and hypocalcemia, but no hyponatremia. Blood biochemistry showed severe muscle but not liver damage and an acute inflammatory response [83]. Most of the changes were dissolved after 48 h of recovery [83].

Prolonged running is also known to induce hemolysis. It has been suggested that hemolysis may lead to a significant loss of red blood cells [84]. However, in a 166-km mountain ultra-endurance marathon, "exercise anemia" was entirely due to plasma volume expansion and not to a concomitant decrease in total red blood cell volume [84].

Apart from these biomarkers, also changes in hormones have been documented [85, 86]. After a 110-km ultramarathon, cortisol was increased and testosterone decreased [85]. In the 1000 km Sydney to Melbourne ultramarathon, resting serum conjugated catecholamines such as epinephrine, norepinephrine, dopamine, free epinephrine, and free dopamine were significantly elevated above the normal mean [86]. Adrenocorticotropic hormone (ACTH) levels were significantly elevated above the normal range. Immunoreactive beta-endorphin, growth hormone, prolactin, testosterone, cortisol, and cortisol-binding globulin were within the normal range. After the race, catecholamines, free and conjugated, remained significantly elevated above the normal mean. ACTH remained elevated and immunoreactive beta-endorphin within the normal range. A significant increase in growth hormone, prolactin, and cortisol was seen, with no change in cortisol-binding globulin. The authors concluded that these ultramarathoners demonstrated a significantly altered baseline hormonal state as a model of chronic physical stress [86]. This may represent hormonal adaptation to prolonged stress.

13.5.3 Ultra-running and Skeletal Muscle Damage

Ultramarathon running has a major impact on skeletal muscles [74]. Unfamiliar exercise involving forceful eccentric muscle contractions, such as running downhill, can cause increases in creatine kinase (CK) and delayed onset of muscle soreness that peaks ~36–72 h after the exercise bout [73]. In ultramarathoners, a partially considerable increase in CK can be found postrace [63, 74, 78, 87]. For example, CK was increased 35-fold at the end of a 200-km race and remained increased until day 5 [78]. In another 200-km ultramarathon, CK increased 90-fold postrace [74]. In “Badwater Ultramarathon,” CK can increase up to 27,951 U/l [87]. And in the 161-km “Western States Endurance Run,” 216 (66 %) of 328 finishers had median and mean CK concentrations of 20,850 U/l and 32,956 U/l, respectively, with a range of 1500–264,300 U/l, and 13 (6 %) of the finishers had values greater than 100,000 U/l [88].

The increase in CK seemed to be dependent upon the fitness level of the athlete [63]. Higher levels of training, or previous ultramarathon racing experience, or both, were associated with lower immediate postexercise levels of plasma enzyme activity [63].

Several studies showed that ultramarathon running leads to a substantial decrease in skeletal muscle mass [57, 89, 90]. It has been tried to prevent the decrease in skeletal muscle mass by the intake of amino acids [89]. However, BCAA supplementation before and during a 100-km ultramarathon had no effect on performance, skeletal muscle damage [89], and muscle soreness [90].

13.5.4 Ultra-running and Heart Damage

Several studies investigated a potential damage of ultra-running to the heart since cardiac muscle injury markers such as CK, creatine kinase-myocardial band (CK-MB), cardiac troponin I (cTnI), and cardiac muscle strain marker, N-terminal pro-brain natriuretic peptide (NT-proBNP), were elevated postrace [87, 91, 92]. Also highly sensitive troponin I was released during ultramarathon running [93, 94].

The findings whether a damage of the heart muscle occurs or not are controversial. High-intensity endurance exercise is associated with biochemical abnormalities that may reflect adverse consequences on cardiac structure and biology [94]. In 18 male marathoners with average age of ~53 years competing in a 308-km ultramarathon, a normal CK-MB mass index (<5.0 ng/ml) and the absence of an increase in the cTnI levels after the ultramarathon suggested that no myocardial injury despite an elevation in CK-MB occurred [91]. Also in ultramarathoners competing in “Badwater Ultramarathon ,” strenuous endurance exercise under extreme environmental conditions did not result in structural myocardial damage in well-trained ultra-endurance athletes [87]. Matin et al. [95] showed in 77 % of ultramarathoners an elevated activity of serum CK-MB, but cardiac scintigraphy showed no evidence of myocardial injury.

On the other side, in a study investigating competitors in the two-day “Lowe Alpine Mountain Marathon,” echocardiographic results indicated left ventricular diastolic and systolic dysfunction following cessation of exercise [96]. Humoral markers of cardiac damage were elevated and the elevations of cardiac troponin were suggestive of minimal myocardial damage [96]. After a 24-h ultramarathon, two of 20 runners showed a slight increase in troponin levels. One of them also had simultaneous decrease in left ventricular ejection fraction. Basal echocardiography assessment showed left ventricular hypertrophy in one and increased left atrial volume in five runners [97]. Estorch et al. [98] showed in runners that myocardial MIBG (123I-metaiodobenzylguanidine) activity was decreased after a 4-h run. The degree of reduction of myocardial MIBG activity was related to the distance covered. In a 160-km ultramarathon, reductions in left ventricular function were not significantly associated with changes in cardiac biomarkers [92]. After a 24-h ultramarathon, the stroke dimension and ejection phase indexes continued to decline within the last 6 h of the race but returned to the prerace level 2–3 days after the race [99]. Although the stress of an ultramarathon resulted in a mild reduction in left ventricular function and biomarker release, the mechanisms behind such consequences remain unknown [92].

13.5.5 Ultra-running and the Immune System

It is known that strenuous exercise is associated with tissue damage. This activates the innate immune system and local inflammation [100]. In experienced ultra-endurance runners, alterations in immunoglobulin concentrations after a race suggest an enhanced immune response. These alterations may have a role in the maintenance of subject health after an ultramarathon [100].

Ultramarathoners often suffer postrace upper-respiratory-tract infections [101, 102]. In the “Two Oceans Marathon” in Cape Town, symptoms of upper-respiratory-tract infection occurred in 33.3 % of runners compared with 15.3 % of controls and were most common in those who achieved the faster race times [101]. The incidence in slow runners was no greater than that in controls [101]. Vitamin C supplementation may enhance resistance to postrace upper-respiratory-tract infections that occur commonly in competitive ultramarathon runners and may reduce the severity of such infections [102].

13.5.6 Problems of the Locomotor System

Ultra-running can cause minor problems to the skeletal muscle such as muscle soreness but also major problems to tendons and joints [103–105]. Different recent studies using MRI (magnetic resonance imagining) provided detailed analyses of the problems of the locomotor system such as bursal or presumed peritendineal fluid and/or edematous tissue, cartilage defects, or tibiotalar bone edema-like lesions [106].

The main running-related musculoskeletal injuries in ultramarathoners were Achilles tendinopathy and patellofemoral syndrome [105]. However, it is even possible to run across a continent without an injury [107]. Despite the extreme nature and harsh environments of multiday ultramarathon races, the majority of injuries or illnesses are minor in nature [103, 108]. For example, during a 219-km five-day stage race, lower limb musculoskeletal injuries accounted for 22.2 %, predominantly affecting the knee [109]. In the 1005 km Sydney to Melbourne ultramarathon, 64 injuries were found in 32 runners [103]. The knee (31.3 %) and ankle (28.1 %) regions were most commonly injured. The most common single diagnosis was retropatellar pain syndrome, and Achilles tendinitis and medial tibial stress syndrome were the next most common injuries. Peritendinitis/tendinitis of the tendons passing under the extensor retinaculum at the ankle was common with 19 % of all injuries. In longer ultramarathons such as six-day race, Achilles tendonitis, patellofemoral pain, and tendonitis of the foot dorsiflexors were the three most common injuries [110]). In a 6-day race, the overall rate of injuries sufficiently severe to affect running performance was 60 % [111]. In the “Trans Europe Foot Race” 2009, a 4487 km multistage ultramarathon covering the south of

Europe (Bari, Italy) to the North Cape, an increase in the diameter of the Achilles tendon, intraosseous signals, bone lesions, and subcutaneous edema were found [104]. Interestingly, an increase of diameter of the Achilles tendon and bone signals were thought to be adaptive; subcutaneous edema and plantar fascia edema were related to abortion of the race [104].

Conclusion

Although we know a lot about physiology, anthropometry, training, and performance in these ultramarathoners, we do not know why these persons compete in these races, what motivates them, and why the number of master ultramarathoners increases across years.

References

1. Ultramarathon running; http://www.ultramarathonrunning.com/. Accessed on Apr 2014.
2. Hoffman MD, Fogard K. Demographic characteristics of 161-km ultramarathon runners. Res Sports Med. 2012;20(1):59–69.
3. Hoffman MD, Krishnan E. Exercise behavior of ultramarathon runners: baseline findings from the ULTRA study. J Strength Cond Res. 2013;27(11):2939–45.
4. Hoffman MD, Ong JC, Wang G. Historical analysis of participation in 161 km ultramarathons in North America. Int J Hist Sport. 2010;27(11):1877–91.
5. Fonseca-Engelhardt K, Knechtle B, Rüst CA, Knechtle P, Lepers R, Rosemann T. Participation and performance trends in ultra-endurance running races under extreme conditions – ‘Spartathlon’ versus 'Badwater Ultramarathon'. Extrem Physiol Med. 2013;2(1):15.
6. Eichenberger E, Knechtle B, Rüst CA, Rosemann T, Lepers R. Age and sex interactions in mountain ultramarathon running – the Swiss Alpine Marathon. Open Access J Sports Med. 2012;3:73–80.
7. Krouse RZ, Ransdell LB, Lucas SM, Pritchard ME. Motivation, goal orientation, coaching, and training habits of women ultrarunners. J Strength Cond Res. 2011;25(10):2835–42.
8. Knoth C, Knechtle B, Rüst CA, Rosemann T, Lepers R. Participation and performance trends in multistage ultramarathons-the 'Marathon des Sables' 2003-2012. Extrem Physiol Med. 2012;1(1):13.
9. Parise CA, Hoffman MD. Influence of temperature and performance level on pacing a 161 km trail ultramarathon. Int J Sports Physiol Perform. 2011;6(2):243–51.
10. Wegelin JA, Hoffman MD. Variables associated with odds of finishing and finish time in a 161-km ultramarathon. Eur J Appl Physiol. 2011;111(1):145–53.
11. Costa RJ, Teixeira A, Rama L, Swancott AJ, Hardy LD, Lee B, Camões-Costa V, Gill S, Waterman JP, Freeth EC, Barrett E, Hankey J, Marczak S, Valero-Burgos E, Scheer V, Murray A, Thake CD. Water and sodium intake habits and status of ultra-endurance runners during a multi-stage ultra-marathon conducted in a hot ambient environment: an observational field based study. Nutr J. 2013;12:13.
12. Larsen HB. Kenyan dominance in distance running. Comp Biochem Physiol A Mol Integr Physiol. 2003;136(1):161–70.
13. Wilber RL, Pitsiladis YP. Kenyan and Ethiopian distance runners: what makes them so good? Int J Sports Physiol Perform. 2012;7(2):92–102.
14. Cejka C, Knechtle B, Knechtle P, Rüst CA, Rosemann T. An increased fluid intake leads to feet swelling in 100-km ultra-marathoners – an observational field study. J Int Soc Sports Nutr. 2012;9(1):11.
15. Knechtle B, Rüst CA, Rosemann T. The aspect of nationality in participation and performance in ultramarathon running – a comparison between ‘Badwater Ultramarathon’ and ‘Spartathlon’. OA Sports Medicine. 2013;1:1.
16. Rüst CA, Knechtle B, Knechtle P, Rosemann T. Similarities and differences in anthropometry and training between recreational male 100-km ultramarathoners and marathoners. J Sports Sci. 2012; 30(12):1249–57.
17. Rüst CA, Knechtle B, Knechtle P, Rosemann T. Comparison of anthropometric and training characteristics between recreational male marathoners and 24-hour ultramarathoners. Open Access J Sports Med. 2012;3:121–9.
18. Knechtle B. Ultramarathon runners: nature or nurture? Int J Sports Physiol Perform. 2012;7(4):310–2.
19. Knechtle B, Rüst CA, Knechtle P, Rosemann T. Does muscle mass affect running times in male longdistance master runners? Asian J Sports Med. 2012; 3(4):247–56.
20. Freund W, Weber F, Billich C, Birklein F, Breimhorst M, Schuetz UH. Ultra-marathon runners are different: investigations into pain tolerance and personality traits of participants of the Trans Europe Foot Race 2009. Pain Pract. 2013;13(7):524–32.
21. Knechtle B, Knechtle P, Rosemann T, Lepers R. Predictor variables for a 100-km race time in male ultra-marathoners. Percept Mot Skills. 2010;111(3): 681–93.
22. Hoffman MD. Anthropometric characteristics of ultramarathoners. Int J Sports Med. 2008;29(10): 808–11.
23. Knechtle B, Knechtle P, Schulze I, Kohler G. Upper arm circumference is associated with race performance in ultra-endurance runners. Br J Sports Med. 2008;42(4):295–9.
24. Knechtle B, Wirth A, Knechtle P, Zimmermann K, Kohler G. Personal best marathon performance is associated with performance in a 24-h run and not anthropometry or training volume. Br J Sports Med. 2009;43(11):836–9.

25. Knechtle B, Knechtle P, Rosemann T, Senn O. What is associated with race performance in male 100-km ultra-marathoners–anthropometry, training or marathon best time? J Sports Sci. 2011;29(6):571–7.
26. Arrese AL, Ostáriz ES. Skinfold thicknesses associated with distance running performance in highly trained runners. J Sports Sci. 2006;24(1):69–76.
27. Knechtle B, Knechtle P, Rüst CA, Rosemann T. Leg skinfold thicknesses and race performance in male 24-hour ultra-marathoners. Proc (Bayl Univ Med Cent). 2011;24(2):110–4.
28. Hoffman MD, Lebus DK, Ganong AC, Casazza GA, Van Loan M. Body composition of 161-km ultramarathoners. Int J Sports Med. 2010;31(2):106–9.
29. Knechtle B, Knechtle P, Rosemann T, Lepers R. Personal best marathon time and longest training run, not anthropometry, predict performance in recreational 24-hour ultrarunners. J Strength Cond Res. 2011;25(8):2212–8.
30. Peter L, Rüst CA, Knechtle B, Rosemann T, Lepers R. Sex differences in 24-hour ultra-marathon performance–A retrospective data analysis from 1977 to 2012. Clinics (Sao Paulo). 2014;69(1):38–46.
31. Coast JR, Blevins JS, Wilson BA. Do gender differences in running performance disappear with distance? Can J Appl Physiol. 2004;29(2):139–45.
32. Rüst CA, Knechtle B, Rosemann T, Lepers R. Analysis of performance and age of the fastest 100-mile ultra-marathoners worldwide. Clinics (Sao Paulo). 2013;68(5):605–11.
33. Cejka N, Knechtle B, Rüst CA, Rosemann T, Lepers R, 5. Performance and age of the fastest female and male 100-km ultra-marathoners worldwide from 1960 to 2012. J Strength Cond Res. 2014;29(5):1180–90.
34. Knechtle B, Rüst CA, Rosemann T, Lepers R. Age-related changes in 100-km ultra-marathon running performance. Age (Dordr). 2012;34(4):1033–45.
35. Zingg M, Rüst CA, Lepers R, Rosemann T, Knechtle B. Master runners dominate 24-h ultramarathons worldwide-a retrospective data analysis from 1998 to 2011. Extrem Physiol Med. 2013;2(1):21.
36. Zingg MA, Knechtle B, Rüst CA, Rosemann T, Lepers R. Analysis of participation and performance in athletes by age group in ultramarathons of more than 200 km in length. Int J Gen Med. 2013;6:209–20.
37. Hunter SK, Stevens AA, Magennis K, Skelton KW, Fauth M. Is there a sex difference in the age of elite marathon runners? Med Sci Sports Exerc. 2011;43(4):656–64.
38. Hoffman MD. Performance trends in 161-km ultramarathons. Int J Sports Med. 2010;31(1):31–7.
39. Jampen SC, Knechtle B, Rüst CA, Lepers R, Rosemann T. Increase in finishers and improvement of performance of masters runners in the Marathon des Sables. Int J Gen Med. 2013;6:427–38.
40. Rüst CA, Knechtle B, Eichenberger E, Rosemann T, Lepers R. Finisher and performance trends in female and male mountain ultramarathoners by age group. Int J Gen Med. 2013;6:707–18.
41. Stuempfle KJ, Hoffman MD, Weschler LB, Rogers IR, Hew-Butler T. Race diet of finishers and non-finishers in a 100 mile (161 km) mountain footrace. J Am Coll Nutr. 2011;30(6):529–35.
42. Case S, Evans D, Tibbets G, Case S, Miller D. Dietary intakes of participants in the IditaSport Human Powered Ultra-marathon. Alaska Med. 1995;37(1):20–4.
43. Eden BD, Abernethy PJ. Nutritional intake during an ultraendurance running race. Int J Sport Nutr. 1994;4(2):166–74.
44. Fallon KE, Broad E, Thompson MW, Reull PA. Nutritional and fluid intake in a 100-km ultramarathon. Int J Sport Nutr. 1998;8(1):24–35.
45. Enqvist JK, Mattsson CM, Johansson PH, Brink-Elfegoun T, Bakkman L, Ekblom BT. Energy turnover during 24 hours and 6 days of adventure racing. J Sports Sci. 2010;28(9):947–55.
46. Machefer G, Groussard C, Zouhal H, Vincent S, Youssef H, Faure H, Malardé L, Gratas-Delamarche A. Nutritional and plasmatic antioxidant vitamins status of ultra endurance athletes. J Am Coll Nutr. 2007;26(4):311–6.
47. Hill RJ, Davies PS. Energy expenditure during 2 wk of an ultra-endurance run around Australia. Med Sci Sports Exerc. 2001;33(1):148–51.
48. O'Hara WJ, Allen C, Shephard RJ, Gill JW. LaTulippe--a case study of a one hundred and sixty kilometre runner. Br J Sports Med. 1977;11(2):83–7.
49. Rehrer NJ, Brouns F, Beckers EJ, Frey WO, Villiger B, Riddoch CJ, Menheere PP, Saris WH. Physiological changes and gastro-intestinal symptoms as a result of ultra-endurance running. Eur J Appl Physiol Occup Physiol. 1992;64(1):1–8.
50. Baska RS, Moses FM, Graeber G, Kearney G. Gastrointestinal bleeding during an ultramarathon. Dig Dis Sci. 1990;35(2):276–9.
51. Simons SM, Kennedy RG. Gastrointestinal problems in runners. Curr Sports Med Rep. 2004;3(2):112–6.
52. Glace B, Murphy C, McHugh M. Food and fluid intake and disturbances in gastrointestinal and mental function during an ultramarathon. Int J Sport Nutr Exerc Metab. 2002;12(4):414–27.
53. Knechtle B, Wirth A, Knechtle P, Rosemann T, Senn O. Do ultra-runners in a 24-h run really dehydrate? Ir J Med Sci. 2011;180(1):129–34.
54. Schütz UH, Billich C, König K, Würslin C, Wiedelbach H, Brambs HJ, Machann J. Characteristics, changes and influence of body composition during a 4486 km transcontinental ultramarathon: results from the Trans Europe Foot Race mobile whole body MRI-project. BMC Med. 2013;11:122.
55. Kao WF, Shyu CL, Yang XW, Hsu TF, Chen JJ, Kao WC, Polun-Chang, Huang YJ, Kuo FC, Huang CI, Lee CH. Athletic performance and serial weight changes during 12- and 24-hour ultra-marathons. Clin J Sport Med. 2008;18(2):155–8.

56. Barr SI, Costill DL. Water: can the endurance athlete get too much of a good thing? J Am Diet Assoc. 1989;89(11):1629–32.
57. Knechtle B, Knechtle P, Wirth A, Alexander Rüst C, Rosemann T. A faster running speed is associated with a greater body weight loss in 100-km ultra-marathoners. J Sports Sci. 2012;30(11):1131–40.
58. Knechtle B, Knechtle P, Rosemann T. Do male 100-km ultra-marathoners overdrink? Int J Sports Physiol Perform. 2011;6(2):195–207.
59. Knechtle B, Senn O, Imoberdorf R, Joleska I, Wirth A, Knechtle P, Rosemann T. No fluid overload in male ultra-runners during a 100 km ultra-run. Res Sports Med. 2011;19(1):14–27.
60. Landman ZC, Landman GO, Fatehi P. Physiologic alterations and predictors of performance in a 160-km ultramarathon. Clin J Sport Med. 2012;22(2): 146–51.
61. Hoffman MD, Stuempfle KJ, Rogers IR, Weschler LB, Hew-Butler T. Hyponatremia in the 2009 161-km Western States Endurance Run. Int J Sports Physiol Perform. 2012;7(1):6–10.
62. Knechtle B, Knechtle P, Rosemann T. Low prevalence of exercise-associated hyponatremia in male 100 km ultra-marathon runners in Switzerland. Eur J Appl Physiol. 2011;111(6):1007–16.
63. Noakes TD, Carter JW. The responses of plasma biochemical parameters to a 56-km race in novice and experienced ultra-marathon runners. Eur J Appl Physiol Occup Physiol. 1982;49(2):179–86.
64. Lebus DK, Casazza GA, Hoffman MD, Van Loan MD. Can changes in body mass and total body water accurately predict hyponatremia after a 161-km running race? Clin J Sport Med. 2010;20(3):193–9.
65. Cuthill JA, Ellis C, Inglis A. Hazards of ultra-marathon running in the Scottish Highlands: exercise-associated hyponatraemia. Emerg Med J. 2009;26(12):906–7.
66. Knechtle B, Knechtle P, Rüst CA, Gnädinger M, Imoberdorf R, Kohler G, Rosemann T, Ballmer P. Regulation of electrolyte and fluid metabolism in multi-stage ultra-marathoners. Horm Metab Res. 2012;44(12):919–26.
67. Bürge J, Knechtle B, Knechtle P, Gnädinger M, Rüst CA, Rosemann T. Maintained serum sodium in male ultra-marathoners-the role of fluid intake, vasopressin, and aldosterone in fluid and electrolyte regulation. Horm Metab Res. 2011;43(9):646–52.
68. Knechtle B, Senn O, Imoberdorf R, Joleska I, Wirth A, Knechtle P, Rosemann T. Maintained total body water content and serum sodium concentrations despite body mass loss in female ultra-runners drinking ad libitum during a 100 km race. Asia Pac J Clin Nutr. 2010;19(1):83–90.
69. Knechtle B, Knechtle P, Rosemann T. No exercise-associated hyponatremia found in an observational field study of male ultra-marathoners participating in a 24-hour ultra-run. Phys Sportsmed. 2010;38(4): 94–100.
70. Chlíbková D, Knechtle B, Rosemann T, Zákovská A, Tomášková I. The prevalence of exercise-associated hyponatremia in 24-hour ultra-mountain bikers, 24-hour ultra-runners and multi-stage ultra-mountain bikers in the Czech Republic. J Int Soc Sports Nutr. 2014;11(1):3.
71. Bracher A, Knechtle B, Gnädinger M, Bürge J, Rüst CA, Knechtle P, Rosemann T. Fluid intake and changes in limb volumes in male ultra-marathoners: does fluid overload lead to peripheral oedema? Eur J Appl Physiol. 2012;112(3):991–1003.
72. Cejka N, Rüst CA, Lepers R, Onywera V, Rosemann T, Knechtle B. Participation and performance trends in 100-km ultra-marathons worldwide. J Sports Sci. 2013;32(4):354–66.
73. Bird SR, Linden M, Hawley JA. Acute changes to biomarkers as a consequence of prolonged strenuous running. Ann Clin Biochem. 2014;51(Pt 2):137–50.
74. Kim HJ, Lee YH, Kim CK. Biomarkers of muscle and cartilage damage and inflammation during a 200 km run. Eur J Appl Physiol. 2007;99(4):443–7.
75. Nagel D, Seiler D, Franz H, Jung K. Ultra-long-distance running and the liver. Int J Sports Med. 1990;11(6):441–5.
76. Wu HJ, Chen KT, Shee BW, Chang HC, Huang YJ, Yang RS. Effects of 24 h ultra-marathon on biochemical and hematological parameters. World J Gastroenterol. 2004;10(18):2711–4.
77. Kasprowicz K, Ziemann E, Ratkowski W, Laskowski R, Kaczor JJ, Dadci R, Antosiewicz J. Running a 100-km ultra-marathon induces an inflammatory response but does not raise the level of the plasma iron-regulatory protein hepcidin. J Sports Med Phys Fitness. 2013;53(5):533–7.
78. Kim HJ, Lee YH, Kim CK. Changes in serum cartilage oligomeric matrix protein (COMP), plasma CPK and plasma hs-CRP in relation to running distance in a marathon (42.195 km) and an ultra-marathon (200 km) race. Eur J Appl Physiol. 2009;105(5):765–70.
79. Waśkiewicz Z, Kłapcińska B, Sadowska-Krępa E, Czuba M, Kempa K, Kimsa E, Gerasimuk D. Acute metabolic responses to a 24-h ultra-marathon race in male amateur runners. Eur J Appl Physiol. 2012; 112(5):1679–88.
80. Fallon KE, Sivyer G, Sivyer K, Dare A. The biochemistry of runners in a 1600 km ultramarathon. Br J Sports Med. 1999;33(4):264–9.
81. McKechnie JK, Leary WP, Noakes TD. Metabolic responses to a 90 km running race. S Afr Med J. 1982;61(13):482–4.
82. Saugy J, Place N, Millet GY, Degache F, Schena F, Millet GP. Alterations of neuromuscular function after the world's most challenging mountain ultra-marathon. PLoS One. 2013;8(6):e65596.
83. Kłapcińska B, Waśkiewicz Z, Chrapusta SJ, Sadowska-Krępa E, Czuba M, Langfort J. Metabolic responses to a 48-h ultra-marathon run in middle-aged male amateur runners. Eur J Appl Physiol. 2013;113(11):2781–93.
84. Robach P, Boisson RC, Vincent L, Lundby C, Moutereau S, Gergelé L, Michel N, Duthil E, Féasson L, Millet GY. Hemolysis induced by an

extreme mountain ultra-marathon is not associated with a decrease in total red blood cell volume. Scand J Med Sci Sports. 2014;24(1):18–27.

85. Fournier PE, Stalder J, Mermillod B, Chantraine A. Effects of a 110 kilometers ultra-marathon race on plasma hormone levels. Int J Sports Med. 1997;18(4):252–6.
86. Pestell RG, Hurley DM, Vandongen R. Biochemical and hormonal changes during a 1000 km ultramarathon. Clin Exp Pharmacol Physiol. 1989;16(5): 353–61.
87. Roth HJ, Leithäuser RM, Doppelmayr H, Doppelmayr M, Finkernagel H, von Duvillard SP, Korff S, Katus HA, Giannitsis E, Beneke R. Cardiospecificity of the 3rd generation cardiac troponin T assay during and after a 216 km ultra-endurance marathon run in Death Valley. Clin Res Cardiol. 2007;96(6):359–64.
88. Hoffman MD, Ingwerson JL, Rogers IR, Hew-Butler T, Stuempfle KJ. Increasing creatine kinase concentrations at the 161-km Western States Endurance Run. Wilderness Environ Med. 2012;23(1):56–60.
89. Knechtle B, Mrazek C, Wirth A, Knechtle P, Rüst CA, Senn O, Rosemann T, Imoberdorf R, Ballmer P. Branched-chain amino acid supplementation during a 100-km ultra-marathon–a randomized controlled trial. J Nutr Sci Vitaminol (Tokyo). 2012;58(1):36–44.
90. Knechtle B, Knechtle P, Mrazek C, Senn O, Rosemann T, Imoberdorf R, Ballmer P. No effect of short-term amino acid supplementation on variables related to skeletal muscle damage in 100 km ultra-runners – a randomized controlled trial. J Int Soc Sports Nutr. 2011;8:6.
91. Kim YJ, Shin YO, Lee JB, Lee YH, Shin KA, Kim AC, Goh CW, Kim C, Oh JK, Min YK, Yang HM. The effects of running a 308 km ultra-marathon on cardiac markers. Eur J Sport Sci. 2014;14(1):92–7.
92. Scott JM, Esch BT, Shave R, Warburton DE, Gaze D, George K. Cardiovascular consequences of completing a 160-km ultramarathon. Med Sci Sports Exerc. 2009;41(1):26–34.
93. Lippi G, Schena F, Salvagno GL, Tarperi C, Aloe R, Guidi GC. Comparison of conventional and highly-sensitive troponin I measurement in ultra-marathon runners. J Thromb Thrombolysis. 2012;33(4):338–42.
94. Salvagno GL, Schena F, Gelati M, Danese E, Cervellin G, Guidi GC, Lippi G. The concentration of high-sensitivity troponin I, galectin-3 and NT-proBNP substantially increase after a 60-km ultramarathon. Clin Chem Lab Med. 2014;52(2):267–72.
95. Matin P, Lang G, Carretta R, Simon G. Scintigraphic evaluation of muscle damage following extreme exercise: concise communication. J Nucl Med. 1983;24(4):308–11.
96. Shave RE, Dawson E, Whyte G, George K, Ball D, Gaze DC, Collinson PO. Evidence of exercise-induced cardiac dysfunction and elevated cTnT in separate cohorts competing in an ultra-endurance mountain marathon race. Int J Sports Med. 2002;23(7):489–94.
97. Passaglia DG, Emed LG, Barberato SH, Guerios ST, Moser AI, Silva MM, Ishie E, Guarita-Souza LC, Costantini CR, Faria-Neto JR. Acute effects of prolonged physical exercise: evaluation after a twenty-four-hour ultramarathon. Arq Bras Cardiol. 2013; 100(1):21–8.
98. Estorch M, Serra-Grima R, Carrió I, Flotats A, Lizárraga A, Bernà LL, Prats T, Segura R. Influence of prolonged exercise on myocardial distribution of 123I-MIBG in long-distance runners. J Nucl Cardiol. 1997;4(5):396–402.
99. Niemelä KO, Palatsi IJ, Ikäheimo MJ, Takkunen JT, Vuori JJ. Evidence of impaired left ventricular performance after an uninterrupted competitive 24 hour run. Circulation. 1984;70(3):350–6.
100. McKune AJ, Smith LL, Semple SJ, Wadee AA. Influence of ultra-endurance exercise on immunoglobulin isotypes and subclasses. Br J Sports Med. 2005;39(9):665–70.
101. Peters EM, Bateman ED. Ultramarathon running and upper respiratory tract infections. An epidemiological survey. S Afr Med J. 1983;64(15):582–4.
102. Peters EM, Goetzsche JM, Grobbelaar B, Noakes TD. Vitamin C supplementation reduces the incidence of postrace symptoms of upper-respiratory-tract infection in ultramarathon runners. Am J Clin Nutr. 1993;57(2):170–4.
103. Fallon KE. Musculoskeletal injuries in the ultramarathon: the 1990 Westfield Sydney to Melbourne run. Br J Sports Med. 1996;30(4):319–23.
104. Freund W, Weber F, Billich C, Schuetz UH. The foot in multistage ultra-marathon runners: experience in a cohort study of 22 participants of the Trans Europe Footrace Project with mobile MRI. BMJ Open. 2012:22;2(3).
105. Lopes AD, Hespanhol Júnior LC, Yeung SS, Costa LO. What are the main running-related musculoskeletal injuries? A Syst Review Sports Med. 2012; 42(10):891–905.
106. Theysohn JM, Kraff O, Maderwald S, Kokulinsky PC, Ladd ME, Barkhausen J, Ladd SC. MRI of the ankle joint in healthy non-athletes and in marathon runners: image quality issues at 7.0 T compared to 1.5 T. Skeletal Radiol. 2013;42(2):261–7.
107. Lathan SR, Cantwell JD. A run for the record. Studies on a trans-American ultramarathoner. JAMA. 1981;245(4):367–8.
108. Krabak BJ, Waite B, Schiff MA. Study of injury and illness rates in multiday ultramarathon runners. Med Sci Sports Exerc. 2011;43(12):2314–20.
109. Scheer BV, Murray A. Al Andalus Ultra Trail: an observation of medical interventions during a 219-km, 5-day ultramarathon stage race. Clin J Sport Med. 2011;21(5):444–6.
110. Bishop GW, Fallon KE. Musculoskeletal injuries in a six-day track race: ultramarathoner's ankle. Clin J Sport Med. 1999;9(4):216–20.
111. Hutson MA. Medical implications of ultramarathon running: observations on a six day track race. Br J Sports Med. 1984;18(1):44–5.

Skateboarding Injuries

14

Thomas Lustenberger
and Demetrios Demetriades

14.1 Skateboarding

14.1.1 Historical Overview

14.1.1.1 1940s to 1960s

Skateboarding was born at some point in the late 1940s or probably early 1950s. It has its roots in the culture of surfing, when surfers in California wanted something to surf when the waves were flat. The first skateboarders started with wooden boxes or boards with roller skate wheels attached to the bottom. In late 1944, French children were seen in the Montmartre section of Paris, riding on boards with roller skate wheels attached to them [1]. During this time, skateboarding was seen as something to do for fun besides surfing and was often called "sidewalk surfing." The first manufactured skateboards were ordered by a surf shop in Los Angeles, meant to be used by surfers in their downtime [2].

14.1.1.2 1970s

In the early 1970s, specifically designed skateboard wheels made of polyurethane were developed. Until this point, skateboarders used clay or even metal wheels [3]. The improvement in traction and performance offered by this new material was so immense, that from the wheel's release in 1972, the popularity of skateboarding started to rise rapidly, causing companies to invest more in product development. As a result of the improved handling of skateboards, skateboarders started inventing new tricks. In particular, skating vertical walls of empty swimming pools was invented in 1976, which started the "vert" trend in skateboarding. Likewise, the "freestyle" movement in skateboarding became a much more specialized discipline, characterized by the development of a wide assortment of flatground tricks.

In March 1976, the first two skate parks were opened to the public (Skateboard City Skate Park in Port Orange, Florida, and Carlsbad Skate Park in San Diego County, California) [4]. They were the first of some 200 skate parks that would be built through 1982 [2]. However, particularly as a result of the increasing "vert" skating movement and the development of more dangerous tricks, skate parks were faced with liability concerns and increased insurance costs to skate park owners. Consequently, many parks had to close, and by the beginning of the 1980s, skateboarding had declined in popularity.

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14.1.1.3 1980s

Skateboard companies run by skateboarders mainly dominated this time period. The focus was initially on vert ramp skateboarding. However, the majority of skateboarders did not have access to ramps; therefore, street skating increased in popularity. Skaters sought out shopping centers and public and private property as a place to skate, leading to public opposition, in which businesses, governments, and property owners banned skateboarding on properties under their jurisdiction or ownership. Combined with the decline of vert skating, by 1992 only a small fraction of skateboarders remained, practicing a highly technical version of street skating.

14.1.1.4 1990s

Skateboarding during the 1990s became dominated by street skateboarding. While board styles have seen a dramatic evolution since the 1970s, they have remained mostly unchanged since the mid-1990s. The contemporary shape of the skateboard is derived from the freestyle boards of the 1980s, with a largely symmetrical shape and relatively narrow width.

14.1.1.5 2000 to Present

By 2001, skateboarding had gained in popularity again. The number of skateboarders worldwide increased by more than 60 % between 1999 and 2002 – from 7.8 to 12.5 million [2]. Many cities also began implementing recreation plans and statutes as part of their vision to make public lands more available, in particular for skateboarding. By 2006, there were over 2400 skate parks worldwide [2].

14.1.2 Skateboard Design: Parts of a Skateboard

The size and shape of the skateboards has been changing over time to meet the needs and demands of riders, reflecting the changing interests and styles of skaters. A traditional skateboard consists of three basic elements: the board (or deck), wheels, and trucks, which connect the wheels to the board and allow the board to turn [5].

14.1.2.1 Wheels

The wheels of a skateboard, usually made of polyurethane, are produced in many different sizes and shapes to suit the different types of skating. Larger sizes (55–85 mm) roll faster. Smaller sizes (48–54 mm) keep the board closer to the ground, require less force to accelerate, and produce a lower center of gravity but also make for a slower top speeds [5]. Wheels are available in a variety of hardnesses. Riders choose between wheels with minor differences in size, shape, and hardness, depending on the type of skating they want to do [6].

14.1.2.2 Deck or Board

Modern decks vary in size, but most are 20–25 cm wide and 70–85 cm long. Wider decks can be used for greater stability when transition or ramp skating. They are traditionally made from plies of sugar maple veneers, pressed together using polyvinyl glues. A grip tape, with a surface similar to fine sandpaper, is usually applied to the top surface of a board, to allow the rider's feet to grip the surface and help the skater to stay on the board while doing tricks [5].

14.1.2.3 Trucks

Attached to the deck are two metal trucks, which connect to the wheels. The trucks are further composed of two parts: the top part (called the *baseplate*) is screwed to the deck, while the axle runs through the part beneath, called the *hanger* (Fig. 14.1).

Between the baseplate and the hanger are the bushings that provide the cushion mechanism for turning the skateboard. The stiffer the bushings, the more resistant the skateboard is to turning. A bolt called a "kingpin" holds these parts together and fits inside the bushings. Thus by tightening or loosening the kingpin nut, the trucks can be adjusted loosely for better turning and tighter for more stability [5, 6].

14.1.3 Skateboarding Styles

A basic understanding of the skateboarding style or trick performed while being injured might help

Fig. 14.1 The side of a skateboard with the deck, truck, and wheels (Photo taken with permission at Railside Skateshop, Frankfurt/Main, Germany)

the physician to identify certain injuries and might allow him to estimate the severity of injury. Unfortunately, up to now, data on injuries suffered while performing specific skateboarding styles or tricks do not exist. Similarly, there are no figures for injuries suffered in competitive environments and by professional skateboarders [7]. Styles of skateboarding have evolved over time and are influenced by a number of factors, including sociocultural factors, mass media, and technology [7]. Styles can be broadly divided into two different categories: skateboarding to perform tricks and skateboarding as a means of transportation.

14.1.3.1 Freestyle Skateboarding

Probably the oldest style of skateboarding, freestyle skateboarding developed from the use of skateboards as a mode of transport in the 1960s. The style changed significantly with the introduction of *ollies* (see below) and other tricks in the 1970s and 1980s and the introduction of various obstacle elements [8].

14.1.3.2 Vert Skateboarding

Vert skateboarding has its origin, as previously described, in "pool riding" – the riding of skateboards in emptied backyard swimming pools – during the 1970s. It involves skateboard riders moving from the horizontal (on the ground) to the vertical (on a ramp or other incline) to perform tricks – hence the term "vert."

14.1.3.3 Street Skateboarding

Street skateboarding involves the use of urban obstacles like stairs and their handrails, benches, and other street furniture. Skaters perform tricks around, on, onto, or over these obstacles [8].

14.1.3.4 Park Skateboarding

Park skateboarding encompasses a variety of substyles adopted by those who ride skateboards in purpose-built skate parks. Most skate parks combine half-pipes and quarter pipes with various other "vert" skateboarding features, as well as "street" obstacles, such as stairs and rails.

14.1.3.5 Cruising

Skateboarding is done with any type of skateboard, where riders travel as fast as possible on ramps and through skate parks or general urban areas without tricks for as long as possible without stopping or touching surfaces.

14.1.3.6 Downhill Skateboarding

Noncompetition downhill skateboarding is one of the oldest styles of skateboarding and was popular in the early 1970s, [8]. Modern riders often use longboards for races, but some use regular skateboards for noncompetition downhill skateboarding.

14.1.4 Skateboarding Tricks

There are a countless number of tricks in skateboarding (Figs. 14.2, 14.3, and 14.4); the purpose here is only to give an idea of the type of performance.

Fig. 14.2 *Feeble grind. Grinds* are tricks in which the trucks of a skateboard, rather than the wheels, are used to slide along an object. This is a *grind* in which the back truck slides along a rail, while the front truck hangs over the rail's far side. Rider: Oliver Gordon. 24 September 2012, Wörgl, Austria (Photo courtesy of Nicola Debernardi)

The *hippie jump and* the *ollie* are fundamental skateboarding tricks, often used as the basis of other more complicated tricks.

14.1.4.1 The "Hippie Jump"

In the hippie jump, a skateboarder rides along on a flat horizontal surface at a certain velocity. He then jumps straight up without exerting any horizontal force on the board. This allows him to fly through the air at the same horizontal velocity as the board. As a result, the board remains directly below him and he is able to land on top of it [9].

14.1.4.2 The "Ollie"

The beginning of the ollie consists of two basic actions, occurring at roughly the same time. The first action is the skateboarder jumping up and off the board. This is accompanied by him pushing down quickly on the tail end of the board, causing it to rebound off the ground and bounce back up. The skateboarder then guides the board along with his feet as it flies through the air, enabling him to land back on top of it (Fig. 14.4) [9].

14.2 Skateboarding Injuries

In the last 20 years, there has been an explosion of both the popularity of adventure and extreme sports and the participation in these activities, with skateboarding at the forefront [10]. Professional skateboarders are able to control their bodies and their boards at speeds of up to 40 miles an hour, performing complex maneuvers and tricks using various equipments such as ramps, rails, banks, ledges, and half-pipes.

As in any other sport, youngsters and amateurs are attempting to imitate those professional athletes. However, with many recreational participants lacking the necessary skills, injuries are common and can sometimes be catastrophic.

14.2.1 Statistics and Demographics

According to the National Sporting Goods Association, in 2010 in the Unites States, nearly 8 million individuals over 7 years of age participated in skateboarding more than once [11]. The vast majority of injuries occur in males, with numerous studies reporting figures exceeding 90 % [12–14]. The average age of injured skateboarders shows a variation from the mid-to-late teens up to >20 years of age, with some studies reporting injuries in skateboarders aged 40 years and older [13, 15]. The wide variation is partially explained by the different data collection methods, from both children's hospitals and those focusing on adult medicine.

14.2.2 Skateboard-Associated Injuries

The first published report on skateboard injuries dates back to the late 1960s [16]. Since then, a continuous flow of reviews of skateboard-related

Fig. 14.3 *Stalefish*, a trick in which the rider jumps high and grabs the skateboard in the middle with his backhand, between the feet on the side of his heels (heel side). August 2012. Rider: Jake Collins, Amsterdam, the Netherlands (Photo courtesy of Nicola Debernardi)

injuries and descriptive studies have been published, warning of potentially serious or catastrophic injuries.

According to the National Electronic Injury Surveillance System (NEISS), it was estimated that approximately 144,000 injuries related to skateboard riding presented to hospital emergency departments in 2009 across the United States, with the vast majority affecting males under the age of 24 years [17]. It was further estimated that of these injuries affecting children, just over 3000 were of a serious nature [7]. In the study by Everett, the estimated skate park injury rate was 1.1 per 1000 users [18]. Fountain found a non-skate park injury rate of 7.0–7.5 per 1000 participants [19]. However, it is important to note that minor injuries and injuries of lesser severity treated in environments other than emergency departments will go unreported and are insufficiently captured by data sets.

14.2.3 Mechanisms and Environmental Location of Injury

Injuries in skateboarding may occur for a variety of reasons. Loss of balance and irregularities in the riding surface (stone, kerb, step, gaps between paving stones, etc.) account for the majority of injuries. Failure when attempting a trick or a jump, collision with a vehicle or an object, and skidding are other frequently reported mechanisms of injury. Depending on the specific trick attempted, the speed and the type of fall, the resulting injuries widely differ. Furthermore, new tricks are likely to change the pattern of injury.

Skateboarding parks are built to provide a safe and supervised area for skaters away from the dangers of traffic and to provide an environment containing specific obstacles designed for skateboarding (Fig. 14.5).

Fig. 14.4 Ollie. Rider: Sjoerd Vissers. 25 October 2012, Eindhoven, the Netherlands (Photo courtesy of Nicola Debernardi). In their tricks, skateboarders often *grab* their skateboard in different ways (Fig. 14.3) and combine aerials with rotation)

Fig. 14.5 Riding in a skateboarding park. Rider: Timothy Scott Misagal. California, USA 2014 (Photo courtesy of Nicola Debernardi)

Potential safety advantages of skateboard parks are numerous: good lighting, regularly maintained skating surfaces, routine structural inspection, and upkeep, enclosed areas that effectively eliminate external factors such as cars, buses, sidewalk cracks, street potholes, stones, and pedestrian traffic. Such distractions have been implicated as significant factors contributing to injury among in-line skaters and skateboarders. Skateboard parks avert these aspects and therefore represent a cleaner, more controlled skating area [18]. Despite this, many boarders still choose to skate on roads, footpaths, and parking lots, and in other public areas. Kyle and colleagues found that those requiring hospitalization were 11.4 times more likely to have been injured on a street by a motor vehicle than nonhospitalized injured skateboarders [20]. Not surprisingly, several hospitals report an increase in the frequency of skateboarding injuries when a skate park has opened nearby [18, 21].

Sheehan reported that fractures sustained in skate parks were more severe and had a severalfold higher risk of requiring manipulation or an invasive treatment when compared to injuries suffered on the street [21]. Explanations for these findings may be that in parks, more experienced skaters are attempting more complicated maneuvers, are skating faster, and therefore suffer more serious injuries. Studies investigating the specific impact of skate park design on injuries found that more injuries occurred in the ramp and bar areas compared to the half-pipe and gully areas [18]. It was suggested that this may be because the ramps and bars are the most popular attractions to the skate park users, since these design features have been popularized through commercially sponsored and televised skating competitions.

14.2.4 Injury Severity

Reported injury severity varies between the different studies. Konkien and colleagues reported a mean Injury Severity Score (ISS) of 10.5 points, which was comparable with in-line skating (10.6 points) and cycling (12.7 points) [22]. In an analysis by the National Trauma Databank (NTDB) including 2270 patients, the mean ISS was 8.6 (standard deviation 5.7), with 16.2 % of the patients sustaining severe (ISS ≥ 16) and 3.3 % sustaining critical (ISS ≥ 25) injuries [13]. The same analysis revealed an age-dependent injury pattern and severity of injuries. The incidence of severe injuries was more than 5 times more likely, and the incidence of critical injuries was more than 4 times more likely in skateboarders older than 16 years as compared to boarders younger than 10 years (Table 14.1) [13]. It is hypothesized that as skateboarders become older, and throughout their adolescent years, their physical attributes change, and their experience allows them to attempt more dangerous maneuvers at greater speeds. However, other studies found opposite results, with all catastrophic injuries sustained by those younger than 20 years of age, mentioning the long-held theory that younger children are more susceptible to head injury, due to their high center of mass and psychomotorial underdevelopment [7, 19].

Table 14.1 Skateboard-related injuries: incidence of injury severity score >15, and ≥25 in 2270 admitted skateboarders according to age groups

Injury severity score	Age group (years)	%	p-value[a]	OR (95 % CI)[a]
>15	<10	5.4	–	1.0
	10–16	13.5	0.002	2.72 (1.41–5.25)
	>16	23.7	<0.001	5.41 (2.80–10.46)
≥25	<10	1.6	–	1.0
	10–16	1.7	1.0	1.04 (0.31–3.50)
	>16	6.6	0.009	4.23 (1.31–13.72)

Modified from Lustenberger et al. [13]
Abbreviations: *OR* odds ratio, *CI* confidence interval
[a] Age group <10 years used as reference for comparison

14.2.5 Musculoskeletal Injuries

The majority of musculoskeletal injuries are minor, including bruises, superficial wounds, contusions, and sprains. Among the more serious lesions, fractures are the most common type of

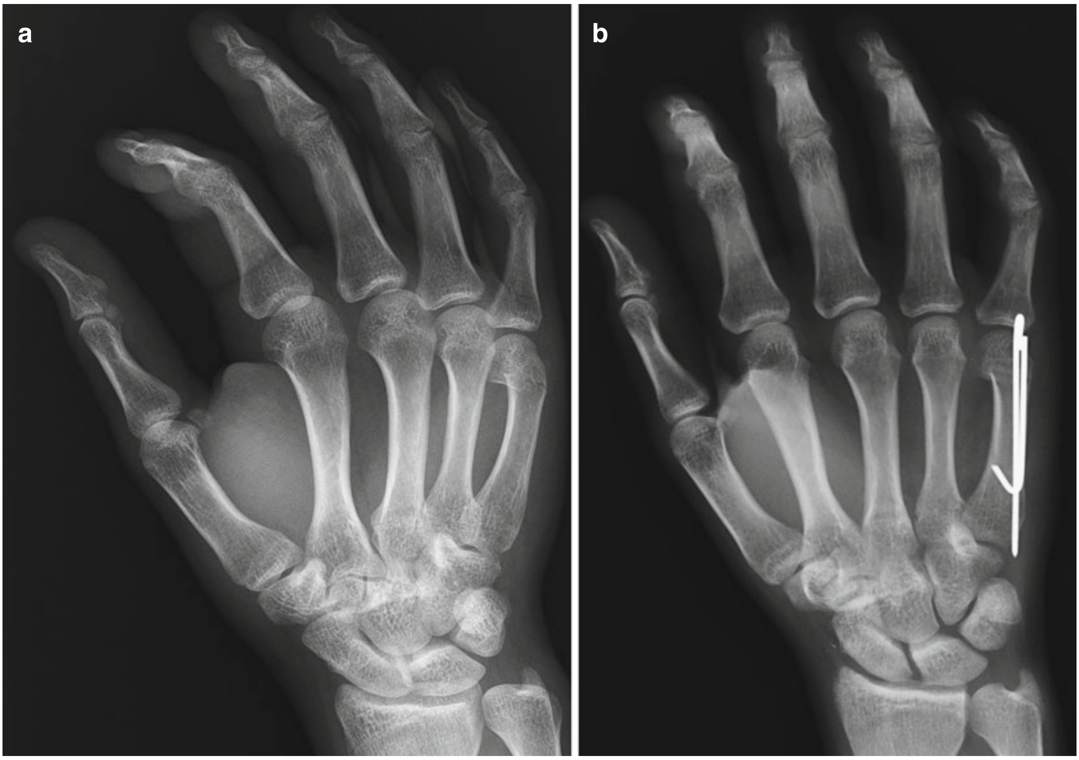

Fig. 14.6 Diagnosis (**a**) and treatment of a distal fracture (skateboarding fracture) of the fifth metacarpal bone in a skateboarder. Treatment involved surgical reduction and fixation using K-wires (**b**) (Courtesy of Dr Feletti, own case series)

skateboard-related injuries. In the literature, the incidence of fractures in patients presenting to emergency departments ranges from 8 % up to 74 % [12, 14, 23]. Due to falling on outstretched arms, the fractures most commonly involve the upper extremity with the hand, wrist and forearm as the most frequently injured site (50 % or greater in several studies) [12, 14, 22, 24] (Fig. 14.6). Olecranon fractures (also called "skateboard elbow") and fractures of the scaphoid, the metacarpal bones, and the phalanges have been reported and, however, are seen less frequently. Fractures in the lower extremity mainly involve the ankle (4.3–23 %) and foot (Fig. 14.7).

In the study by Zalavaras, approximately 6 % of the skateboard-related fractures were open [14]. In particular, open fractures of the forearm or the distal radius were reported to be almost 20 times more likely to be due to skateboarding than roller skating or scooter riding in pediatric patients. Moreover, 63 % of the open forearm fractures seen in children in this institution during the study period resulted from skateboard accidents.

Specific attention should be given to the incidence of physeal injuries. Unfortunately, relatively few studies make specific mention of physeal involvement [14, 25]. In the study by Zalavaras and colleagues, 33 % of the fractures involved the physis, with 22 % of these being displaced. Displaced physeal fractures were most commonly seen in the distal radius (57 %), followed by the distal tibia (29 %) and the distal fibula (14 %) [14].

In several studies, an age-dependent fracture pattern was discussed. Skateboarders younger than 10 years of age were at significantly higher risk of having a fracture of the upper extremity, including the humerus and radius/ulna, compared to skateboarders >16 years. Similarly, femur fractures were more likely in younger children. Contrary to this, older boarders were at higher risk

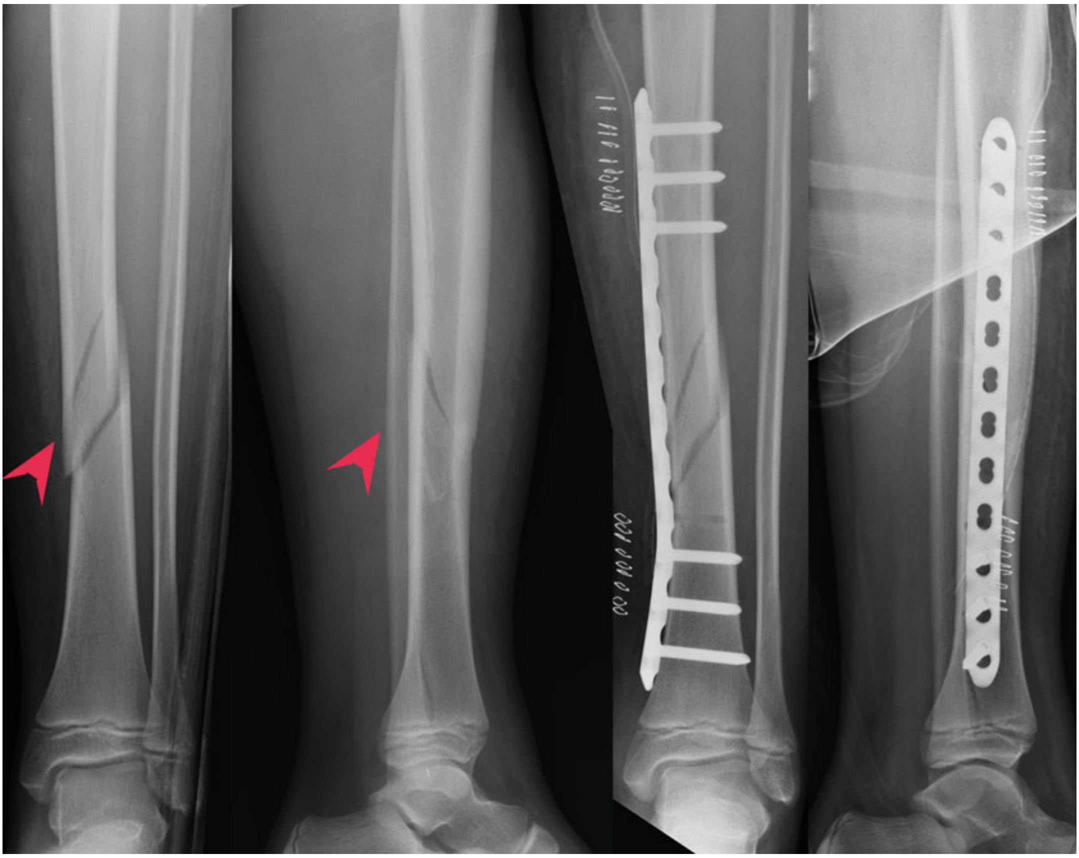

Fig. 14.7 Diagnosis (**a**) and treatment of a spiral tibial fracture in a young skateboarder. Treatment involved surgical reduction and fixation using plate osteosynthesis (**b**) (Courtesy of Dr Feletti, own case series)

for sustaining tibia or fibula fractures (Table 14.2) [13]. It can be speculated that younger children lack the coordination and balance of older children and therefore fall in a more uncoordinated way, attempting to break their fall on their outstretched arms, resulting in more upper extremity fractures. Older and more experienced children, however, attempt more complicated maneuvers and are travelling faster, putting the lower extremities at higher risk of injury.

Operative intervention, in particular for orthopedic injuries, are fractures frequently reported with 33 % of patients being operated on [13, 21]. In the study by Sheehan et al., analyzing 207 children that presented to the emergency department with skateboard- or rollerblade-related fractures, 68 % of the fractures sustained in skate parks required surgery, as opposed to 12 % from street-related injuries [21]. This resulted in a relative risk of 8.35 of a child requiring operative intervention for a fracture sustained while using a skate park. This again may be explained by the fact that in skateboard parks, more complicated maneuvers are attempted and higher speeds are achieved, resulting in more severe injuries.

14.2.6 Head and Face Injuries

Most of the head and face trauma due to skateboarding are minor, consisting of contusions, abrasions, or lacerations. Concussions are reported with an incidence ranging from <1 to 12 %. In the analysis of the NTDB, the overall frequency of traumatic brain injury (TBI) including concussions, severe traumatic brain injury

Table 14.2 Skateboard-related injuries: risk of extremity fractures in 2270 admitted skateboarders according to age groups

Fractures	Age group (years)	%	*p*-value[a]	OR (95 % CI)[a]
Extremity fractures	<10	62.0	–	1.0
	10–16	53.4	0.027	0.70 (0.51–0.96)
	>16	42.0	<0.001	0.44 (0.32–0.62)
Humerus	<10	19.3	–	1.0
	10–16	6.7	<0.001	0.30 (0.20–0.46)
	>16	0.7	<0.001	0.03 (0.01–0.07)
Radius/ulna	<10	18.2	–	1.0
	10–16	25.3	0.035	1.52 (1.03–2.25)
	>16	10.4	0.003	0.52 (0.34–0.81)
Femur	<10	19.3	–	1.0
	10–16	4.3	<0.001	0.19 (0.12–0.30)
	>16	6.0	<0.001	0.27 (0.17–0.43)
Tibia/fibula	<10	3.7	–	1.0
	10–16	14.6	<0.001	4.40 (2.04–9.51)
	>16	19.8	<0.001	6.34 (2.92–13.76)

Modified from Lustenberger et al. [13]

Abbreviations: *OR* odds ratio, *CI* confidence interval

[a] Age group <10 years used as reference for comparison

(defined as any presence of intracranial hemorrhage), and skull fractures was 36.3 %. Skull fractures were diagnosed in 16.2 %, and intracranial bleeding in 13.4 % of patients, including subdural hemorrhage (3.7 %), subarachnoid hemorrhage (2.3 %), epidural hemorrhage (1.9 %), cerebral contusions (3.5 %), and multiple bleedings (5.0 %) [13]. A recent analysis comparing NTDB data and regional data from a trauma center revealed a three times higher incidence of head and face trauma in the trauma center cohort (67.5 %) in skateboarders 18 years and older [15].

Similar to the age dependency of the fracture pattern and injury severity, a linear increase in TBI incidence was noted with increasing age, with a particularly high frequency of TBI in older skateboarders (24.1 % in skateboarders younger than 10 years, 32.6 % in patients 10–16 years of age, and 45.5 % in patients older than 16 years) (Table 14.3). A risk factor analysis for sustaining a skateboard-related TBI revealed that the use of a helmet, boarding at a designated skateboard park, and age 10–16 years were associated with a lower incidence of severe TBI. Age older than 16 years and male gender were predisposing factors for head injury. In the same study, surgical procedures required for head injuries (3.8 %) were the second most common interventions after orthopedic procedures (33 %) [13].

Little information is available on the clinical outcome or the residual effects of injuries sustained by skateboarders, in particular following head injury. While the overall mortality rate is low (<1 %), the leading cause of death in expired patients is head injury. Retsky reviewed deaths reported among skateboarders and found that more than 90 % of deaths were caused by severe head injury [26].

14.2.7 Thoracic and Abdominal Trauma

Thoracic and abdominal injuries are infrequent among skateboarders. Case reports of splenic ruptures, renal lacerations, retroperitoneal hematomas, and scroto-abdominal impalement injury associated with skateboard riding have been published [13, 24, 27, 28]. Thoracic injuries reported included rib fractures and hemo-/pneumothoraces and, however, are even less commonly reported than intra-abdominal trauma (1.2 vs. 5.6 %) [13]. Surgical interventions for thoraco-abdominal injuries mainly include laparotomies with splenectomies/splenorrhaphies as the most frequent types of procedures.

Table 14.3 Skateboard-related injuries: risk of specific head injuries in 2270 admitted skateboarders according to age groups

Traumatic brain injury	Age group (years)	%	p-value[a]	OR (95 % CI)[a]
Overall traumatic brain injury	<10	24.1	–	1.0
	10–16	32.6	0.019	1.52 (1.07–2.17)
	>16	45.5	<0.001	2.64 (1.83–3.79)
Skull fracture	<10	8.0	–	1.0
	10–16	15.0	0.01	2.02 (1.17–3.50)
	>16	20.3	<0.001	2.92 (1.67–.09)
Severe traumatic brain injury	<10	8.6	–	1.0
	10–16	10.8	0.348	1.30 (1.0.75–2.23)
	>16	19.1	0.001	2.53 (1.47–4.35)
Intracranial hemorrhage	<10	6.4	–	1.0
	10–16	7.8	0.494	1.24 (0.67–2.30)
	>16	16.0	0.001	2.78 (1.50–5.14)
Subdural hemorrhage	<10	1.6	–	1.0
	10–16	2.1	0.789	1.34 (0.40–4.44)
	>16	6.9	0.006	4.54 (1.40–14.69)
Subarachnoid hemorrhage	<10	0.5	–	1.0
	10–16	1.4	0.499	2.73 (0.36–20.51)
	>16	4.3	0.013	8.34 (1.13–61.37)
Epidural hemorrhage	<10	1.1	–	1.0
	10–16	1.6	0.759	1.50 (0.35–6.46)
	>16	2.6	0.282	2.47 (0.57–10.66)

Modified from Lustenberger et al. [13]

Abbreviations: *OR* odds ratio, *CI* confidence interval

[a] Age group <10 years used as reference for comparison

14.3 Protective Equipment and Prevention

Several safety measures have been advocated for skateboarders, the most common being the utilization of a helmet and extremity protective equipment such as wrist guards, elbow pads, and kneepads.

Although no studies have explicitly evaluated the use of safety equipment in the specific context of skateboarding, injury prevention patterns of similar riding styles are likely to be comparable. Bicycle helmets have been shown to have a substantial impact on the reduction and severity of head injuries. Reported data have shown that, in bicycle-related injuries, the use of a helmet can provide a 63–88 % reduction in the risk of facial, head, and brain injury [29].

Wrist guard use by skaters has been demonstrated to decrease the risk of upper extremity injury. Children without wrist guards had a tenfold increased risk of sustaining a wrist fracture. Wearing wrist guards had the potential to reduce wrist injuries by 87 % in one study [30–32]. Furthermore, cadaveric test models have demonstrated that wrist guards decrease the severity of wrist injuries and increase the energy load that the wrist can safely withstand [18]. Similar results were found for the use of elbow pads, where a reduction of elbow injuries by 82 % was observed, and for the use of kneepads, where a reduction of knee injuries by 32 % was observed [30, 32].

However, despite the obvious advantages, the use of these safety devices is still poor among skateboarders, and the compliance with its use is not 100 % even in skate parks where it is mandatory. Rates on the use of protective equipment range from as low as 5 % to over 90 % [21, 33]. The reported low rates of acceptance might be due to the fact that this kind of equipment is still regarded as unfashionable and portrays the individual as inexperienced with limited skills.

The Committee on Injury and Poison Prevention recommends that children who ride skateboards should wear helmets (bicycle helmets or multisport helmets) and protective padding, including wrist guards, elbow pads, and kneepads, to prevent injury. The committee further recommends that skateboards should never be ridden in or near traffic and that "catching a ride," where a skater holds onto a vehicle to gain speed, should not be practiced. Moreover, communities should continue to develop skateboarding parks and encourage youth to practice there. These parks are preferred to home-constructed ramps and jumps, because they are more likely to be monitored for safety and separate the skateboarder from pedestrian and motor vehicle traffic [23].

There is a continuous and tremendous scope to improve education efforts for skateboarders and their parents, teaching them about the risks of the sport as well as techniques to avoid injury, such as proper falling and rolling, and how to attempt tricks safely. However, due to the recreational and mostly unstructured nature of skateboarding, participants tend to learn from their friends or from watching professionals, and very few receive any form of instruction before they start skateboarding [7, 34].

Key Points

- The majority of injuries affect young males.
- The most commonly reported skateboard-associated injuries are fractures of the wrist and forearm, with lower leg and ankle injuries being common as well.
- Serious injuries, in particular severe head injuries, are reported in up to 36 % of skateboarders presenting to an emergency department.
- Most injuries tend to occur from a loss of balance or due to a failed trick leading to a fall.
- Protective equipment, such as helmet, wrist guards, elbow pads, and kneepads are recommended and have the potential to significantly reduce the severity of injuries. However, the use of these safety devices is still poor among skateboarders.

References

1. Olson BM. A WAC's war: reminiscences. Minnesota Historical Society; (Collection of letters and photographs), Minnesota, 1965.
2. Skateboarding. Available at: Wikipedia, the free encyclopedia. http://en.wikipedia.org/wiki/Skateboarding.
3. A Brief History of Skateboarding (p. 1). Available at: http://skateboard.about.com/cs/boardscience/a/brief_history.htm.
4. Doeden M. Skateparks: grab your skateboard. Mankato: Capestone Press; 2002.
5. Skateboard. Available at: Wikipedia, the free encyclopedia. http://en.wikipedia.org/wiki/Skateboard.
6. Exploratorium skateboard science: Equipment. Available at: http://www.exploratorium.edu/skateboarding/skatedesignwheel02.html.
7. Hunter J. The epidemiology of injury in skateboarding. Med Sport Sci. 2012;58:142–57.
8. Skateboarding Styles. Available at: Wikipedia, the free encyclopedia. http://en.wikipedia.org/wiki/Skateboarding_styles.
9. Real world physics problems: the physics of skateboarding. http://www.real-world-physics-problems.com/physics-of-skateboarding.html.
10. Reiman PR, Augustine SJ, Chao D. The action sports athlete. Sports Med. Update 2007;July:2–8.
11. 2010 Youth Participation in Selected Sports with Comparison to 2010. Available at: http://www.nsga.org/i4a/pages/index.cfm?pageid=3494.
12. Forsman L, Eriksson A. Skateboarding injuries of today. Br J Sports Med. 2001;35(5):325–8.
13. Lustenberger T, Talving P, Barmparas G, Schnüriger B, Lam L, Inaba K, Demetriades D. Skateboard-related injuries: not to be taken lightly. A National Trauma Databank Analysis. J Trauma. 2010;69(4):924–7.
14. Zalavras C, Nikolopoulou G, Essin D, Manjra N, Zionts LE. Pediatric fractures during skateboarding, roller skating, and scooter riding. Am J Sports Med. 2005;33(4):568–73.
15. Tominaga GT, Schaffer KB, Dandan IS, Kraus JF. Epidemiological and clinical features of an older high-risk population of skateboarders. Injury. 2013; 44(5):645–9.

16. Schuman SH. Skateboard injuries in a campus community. Clin Pediatr. 1967;6(4):252–4.
17. NEISS home. Available at: http://cpsc.gov/library/neiss.html.
18. Everett WW. Skatepark injuries and the influence of skatepark design: a one year consecutive case series. J Emerg Med. 2002;23(3):269–74.
19. Fountain JL, Meyers MC. Skateboarding injuries. Sports Med. 1996;22(6):360–6.
20. Kyle SB, Nance ML, Rutherford Jr GW, Winston FK. Skateboard-associated injuries: participation-based estimates and injury characteristics. J Trauma. 2002;53(4):686–90.
21. Sheehan E, Mulhall KJ, Kearns S, O'Connor P, McManus F, Stephens M, McCormack D. Impact of dedicated skate parks on the severity and incidence of skateboard- and rollerblade-related pediatric fractures. J Pediatr Orthop. 2003;23(4):440–2.
22. Konkin DE, Garraway N, Hameed SM, Brown DR, Granger R, Wheeler S, Simons RK. Population-based analysis of severe injuries from nonmotorized wheeled vehicles. Am J Surg. 2006;191(5):615–8.
23. American Academy of Pediatrics, Committee on Injury and Poison Prevention. Skateboard and scooter injuries. Pediatrics. 2002;109(3):542–3.
24. Cass DT, Ross F. Skateboard injuries. Med J Aust. 1990;153(3):140, 143–4.
25. Banas MP, Dalldorf PG, Marquardt JD. Skateboard and in-line skate fractures: a report of one summer's experience. J Orthop Trauma. 1992;6(3):301–5.
26. Retsky J, Jaffe D, Christoffel K. Skateboarding injuries in children. A second wave. Am J Dis Child. 1991;145(2):188–92.
27. Kruse P. Splenic rupture – a skateboard accident. Ugeskr Laeger. 1990;152(10):681.
28. Carragher AM, Sulaiman SK, Panesar KJ. Scroto-abdominal impalement injury in a skateboard rider. J Emerg Med. 1990;8(4):419–21.
29. Thompson DC, Rivara FP, Thompson R. Helmets for preventing head and facial injuries in bicyclists. Cochrane Database Syst Rev. 2000;(2):CD001855.
30. Schieber RA, Branche-Dorsey CM, Ryan GW, Rutherford Jr GW, Stevens JA, O'Neil J. Risk factors for injuries from in-line skating and the effectiveness of safety gear. N Engl J Med. 1996;335(22):1630–5.
31. American Academy of Pediatrics, Committee on Accident and Poison Prevention. Skateboard injuries. Pediatrics. 1989;83(6):1070–1.
32. Chapman S, Webber C, O'Meara M. Scooter injuries in children. J Paediatr Child Health. 2001;37(6):567–70.
33. Vaca F, Fox JC, Mai D, Anderson CL, Kwon KT, Wiechmann WF. Skatepark-related injuries in a southern California skatepark and their associated short-term disability and healthcare utilization. Clin J Sport Med. 2005;15(3):142–7.
34. Morgan WJ, Galloway DJ, Patel AR. Prevention of skateboard injuries. Scott Med J. 1980;25(1):39–40.

Kitesports Medicine

Kitesurfing and Snowkiting

15

Francesco Feletti

15.1 Kitesports

The use of kites as a means of propulsion is an extremely ancient practice reported in Asia as far back as the thirteenth century [1]. Their first use in modern extreme sports, however, goes back to the beginning of the 1980s. In kiteboarding, a board is used to glide over the surface of water while snowkiting is practiced on snow using normal snowboards or freestyle skis. These sports have rapidly gained popularity throughout the world, and although the precise number of active athletes is not known, the number of kiteboarders itself has been recently estimated by *World Sailing,* formerly known as ISAF (International Sailing Federation), to be 1.5 million people worldwide [2]. The majority of participants are generally male, and the age of the athletes in kitesurfing ranges between 10 and 75 with a peak between 20 and 50 [3]. Since the equipment can be easily transported, exotic locations have become very popular kite tourism destinations. Kiteboarding also received an important official recognition in 2008 when it was adopted as an international sailing class by the *World Sailing* [2].

15.1.1 Equipment

15.1.1.1 Kites

Power kites (or traction kites) are specially built to transfer the wind force to the athlete. Power kites can be divided into two main types: foil kites and leading inflatable edges. Foil kites are constructed using layers of special, ultra-lightweight, water-repellent and air-tight canvas assembled in a communicating cell structure inflated by the wind which enters the kite through special inlets (Fig. 15.1). Leading edge inflatables consist of a single layer of the same fabric applied to a supporting structure inflated with a pump or a compressor prior to use (Fig. 15.2). Modern foil kites, thanks to the introduction of sleeve valves applied to their ram air structure, also work effectively on the water keeping the air locked in the kite and maintaining a consistent shape for water relaunching. Foil kites do not offer as much flotation as leading edge inflatables, however. They may be filled with water following a long period of immersion and are difficult to use in self-rescue techniques. For these reasons, inflatable kites are still more popular for use on water, while those who use kites mainly on dry land often prefer foil kites since they

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Fig. 15.1 Foil kite. *Arrow* shows one of the inlets through which the wind inflates the kite

occupy less space when stored in a backpack. They are also cheaper, faster to set up and simpler to launch.

Most kites used in kiteboarding measure between 5 and 20 m2. Smaller kites can be used in snowkiting given the same wind conditions since the quota of energy needed to keep the kiter afloat and ride the waves is not required. The length of the lines varies between 20 and 30 m with a thickness of just a few millimeters and a load capacity of approximately 200 kg each. The two lines attached to the two sides of the leading edge are known as front lines and transfer the power of the kite directly to the kiter by way of the chicken loop, a loop device hooked into the kitesurfing harness. The chicken loop forms a semi-permanent attachment between the kite and the kiter; it can be unhooked for special freestyle maneuvers and allows a rapid release for safety reasons (Fig. 15.3). The lines attached to the two trailing edges of the kite (*back lines*) are connected directly to the handlebar, a tubular structure normally in carbon fiber measuring 45–55 cm in length used to steer the kite (Fig. 15.4). Although most traction kites have four lines, some leading inflatable edges have an extra line. This helps maintain the profile of the wing in flight, acts as a safety system, and makes it easier to relaunch in the event of a fall in water.

Fig. 15.2 Inflating a leading edge inflatable kite using a hand pump. La Pared, Fuerteventura

Fig. 15.3 Safety systems. The chicken loop is fitted with a rapid-release system (**a**), allowing the kiter to immediately detach himself from the kite in the event of an incident. This causes the kite to deflate and lose power. A leash keeps the kite connected to the kiter and helps depower the kite completely. The leash is also fitted with its own quick-release system (**b**), allowing the kiter to detach himself from the deflated kite if necessary

15.1.1.2 Harnesses

Different models of harness are available including waist (Fig. 15.5) and seat types. The choice of harness depends on the discipline practiced and on individual preferences. Seat harnesses have a lower tow point. This lends itself to greater stability which in turn allows easier water starts, however they tend to be bulkier and reduce freedom of movement. In addition, the seat-type is fitted with leg loops preventing it from being pulled up the kiter's body and causing discomfort (as can happen with waist-type harnesses). Combo harnesses combine the advantages of waist and seat harnesses. Their shape is similar to waist-type harnesses with the addition of the leg loops typical of seat-type harnesses.

15.2 Kitesurfing

15.2.1 Disciplines and Kiteboards

Modern kiteboarding features a number of different disciplines (Table 15.1), and the kiteboards used change depending on the kind of performance required and the rider's style.

Being more versatile and simpler to use, *twin-tip boards* are the most common type of kiteboard. They derive from wakeboarding and are small and narrow; most measure between 120 and 165 cm in length and between 30 and 46 cm in width. Their symmetrical shape allows the rider to change direction of travel without changing stance on the board, and they are particularly suited to freestyle, free -ride and wakestyle.

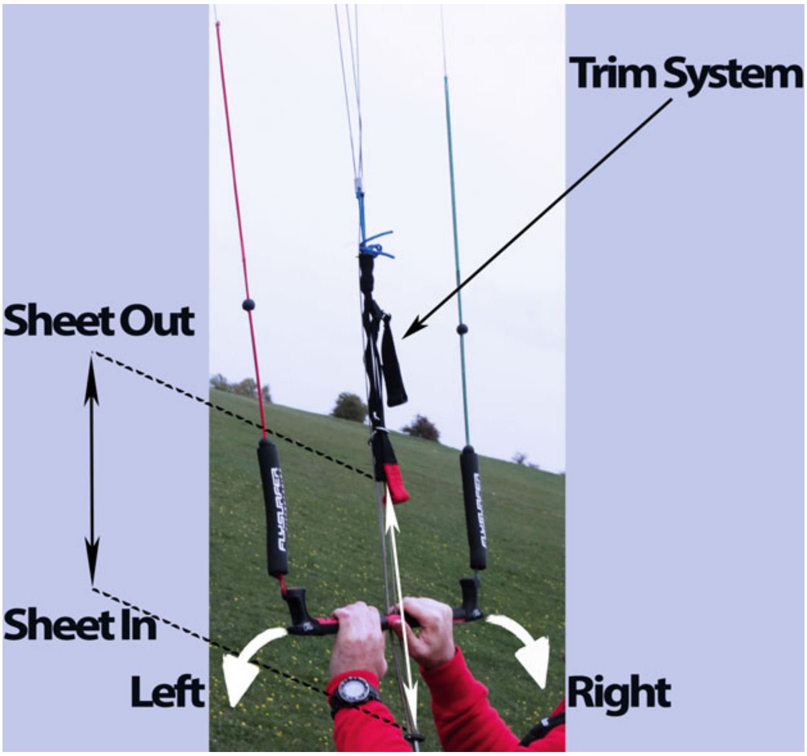

Fig. 15.4 Use and operation of the handlebar. By pulling one side of the bar towards himself, the kiter increases the tension on one of the back lines steering the kite to that side. By pulling the whole bar towards himself, tension is increased on both back lines reducing the angle of incidence of the wind on the kite and increasing the power supplied. A trim system set between the front lines and chicken loop allows the kiter to make fine adjustments in the angle of incidence of the wind on the wing adapting the kite to accommodate for small changes in wind strength

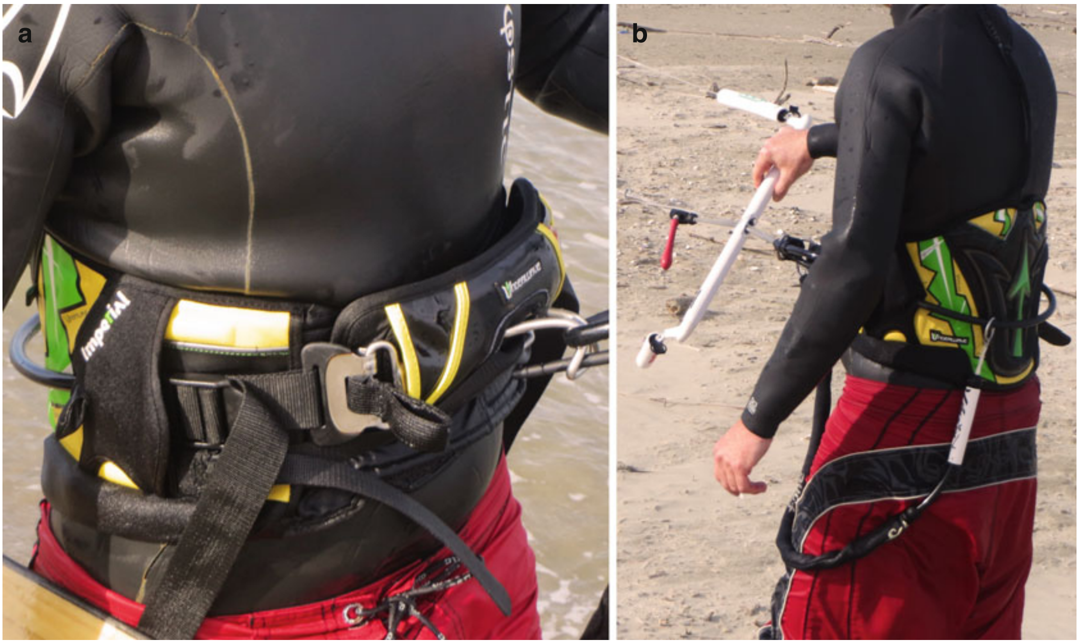

Fig. 15.5 Power-kiting harness (waist type). (**a**) Anterolateral view. (**b**) Posterolateral view. Harnesses have a steel hook connected to a robust system of straps that distribute the forces to the kiter's body

Table 15.1 Main kiteboarding disciplines

Style	Description
Course racing	Similar to yacht racing, this discipline involves racing events along a course, and requires both speed and tactics [4]
Free-ride	An amateur-style discipline, which includes crossing, improvised tricks, and maneuvers of various kinds that are chosen by the rider
Freestyle	This consists of a rider performing jumps, maneuvers, and evolutions of varying technical complexity. Being the "mother" discipline of kitesurfing, it is constantly evolving, and consists of two main styles: known as *old school* and *new school*. Old school was the first style practiced in kitesurfing, it consists of mainly "hooked" evolutions, characterized by high jumps with long phases of flight. New school involves tricks and aerials borrowed from wakeboarding, generally performed with the kite unhooked and at full power
Speed racing	In this discipline the kiter aims to complete a 250 or 500 m course in the fastest time possible, setting speed records with the aid of GPS units
Wave riding	Wave riding combines kiteboarding with surfing; it is practiced using strapless surfboards or specific directional kiteboards

Fig. 15.6 Wave riding in Cape Verde. Rider: Airton Cozzolino. Directional boards are preferred in wave riding: one end is triangular and acts as a prow while the other is wider and fitted with fins (Photo courtesy of Claudio Marosa)

Directional boards travel in one direction only and require a maneuver (tack or jibe) to change orientation. Deriving from windsurfing boards, they are larger than twin-tip boards: they may reach 190 cm in length and 70 cm in width [5]. They are preferred in course racing where their large fins and greater float are used to achieve optimal upwind angles and keep the board gliding even if the wind drops. They are also used for wave riding (Fig. 15.6) where their higher volume and rideability allow the kiter to better interact with the hydrodynamic forces of the waves. A recent innovation in course race board manufacturing has seen the introduction of foil technology where the reduced area of contact with water results in even greater speeds. *Skimboards* are highly technical directional boards mainly used for free riding or wave riding without straps or fins. The discipline of speed racing uses special asymmetric, directional boards – narrow, elongated, and extremely rigid ones. *Mutant boards* have a preferential direction of travel, but they can also travel in the opposite direction. Being built for various purposes, they are mainly used in wave riding.

Most twin-tip boards come with four small fins, two at each end. Directional boards normally have three larger fins at the stern, while those used with fixed structures (kickers or jumps) in wakestyle have no fins attached. The feet are usually fixed to the board by way of sandal-type foot straps, similar to but wider than those used in windsurfing, allowing the feet to be removed quickly from the board as required for

Fig. 15.7 Kitesurfing crossing

certain maneuvers. Bindings are shoe-type attachments that are used particularly in wakestyle by expert riders, while strapless boards are used by some kiters especially in wave riding.

15.3 Kiteboarding Physiology

The study of kiteboarding physiology is difficult due to many factors involved and the fact that the physical demands required are progressively evolving with the diversification of the various disciplines; indeed, there are huge differences between *crossing* (simply gliding on the water crosswind) and *freestyle*.

During crossing with a normal twin-tip board, the rider is attached to the kite and leans backwards towards the water with the upper part of the body facing the direction of travel to balance the traction of the kite (Fig. 15.7). The knees maintain an angle of between 135° and 150° while the elbow remains bent at approximately 90° to exert the traction on the handlebar needed to maintain an adequate tension of the back lines. In this position, the towing force of the kite on the waist keeps the lumbar spine in hyperextension, and the abdominal muscles perform an isometric effort to counteract lordosis. On the other hand, the effort performed by thigh muscles to counteract the push of the water against the board is prevalently isometric, but it is interrupted by the small flexion and extension movements of the hips and knees required to follow the waves and adjust the course in response to changes in wind direction and strength.

Vercruyssen et al. [6] estimated the physiological demands of crossing based on heart rate (HR) taking it as an estimation of the VO2 and measuring the blood lactate concentration (Lab). The physical effort involved in kitesurfing, similarly to that required in Laser sailing, is characterized by considerable increases in HR and blood pressure, maybe because the isometric contraction of large muscle masses limits blood supply due to the compression of blood vessels by muscle fibers. At the same time, however, low values of Lab were found. The discontinuous nature of isometric effort due to the associated dynamic movements required during kiteboarding actually allows the muscles to rest, reducing the sensation of fatigue or preventing its onset [7]. Despite this, the fatigue resulting from an average 30–40 min course racing session may be significant to the extent of affecting performance [8, 9], therefore an adequate level of athletic preparation is essential for those who

Fig. 15.8 Rider: Marco Tagliaferri. Location: Porto Corsini, Ravenna, Italy. A jump using the lift of the kite - explanation in the text (Photo: Roberto Mori)

wish to compete. Overall, when done in light winds (12–15 knots), crossing is a prevalently aerobic effort. Energy expenditure during crossing can be favorably compared with Laser sailing and windsurfing, resulting in a moderately intense activity with an average HR in the range of 72–85 % of the maximum HR. The beginning of the glide requires a greater expenditure of energy since more effort is necessary to position the board correctly on the water and manage the kite. After a few minutes, the HR stabilizes at slightly lower levels, probably due to the kiter's ability to assume the most comfortable position once the board has begun to glide over the water, optimizing the efficiency of the kitesurf at the same time.

Various tricks are performed during freestyle such as jumps and maneuvers. Jumps can be performed by pushing with the legs as in wakeboarding, using a wave as a trampoline as in windsurfing, or using the lift of the kite. The latter technique permits spectacular jump maneuvers and is typical of kiteboarding. To use the lift of the kite, the jump is prepared by maximizing the tension on the lines which is done by directing the board into the wind during crossing. In this phase, the isometric effort performed by the kiter increases considerably, and many kiters report irritation or pain in the joints of the lower limbs and the abdominal muscles during this initial phase of more demanding jumps [8, 9] (Fig. 15.8). A slight flexion of the hips is also required to prepare the slight push needed to help the rider take off from the surface of the water [8]. The jump begins when kiters suddenly invert the direction of flight of the kite, abruptly discharging the energy accumulated in the previous phase towards the zenith, which lifts them into the air.

The jump can lift the kiter to a height of several meters, and the flight phases can last several seconds. Various types of tricks can then be performed during the hang time such as horizontal and vertical rotations or grabs with particular positions of the body. The sequences of movements executed during this phase are similar to those of gymnastics including extension of the limbs and bust, crouches and flexion of the limbs and torso, and grasping of the board – all involving different types of physical effort. The descent phase is slow, and the kiter exploits the parachute effect of the kite by modifying the tension on the lines. During landing, the legs bend and absorb part of the impact while the vertical deceleration of the body is partly neutralized by the upward traction of the kite which resumes its flight in the original direction. The effort of the postural muscles, especially those of the back and the abdomen, allow the body to take up the correct position for landing, while the lower limb muscles contract during landing.

Overall, freestyle is an intense activity involving both aerobic and anaerobic metabolisms. During a freestyle event in mid-wind conditions (ranging from 15 to 22 knots), the average HR was quantified as 85.4 ± 3.0 % of the maximum HR, and VO2 values were estimated as 80.0 ± 4.5 % of the maximum oxygen uptake, while mid-values for Lab of 5.2 ± 0.8 % mmol/L were observed at the end of the freestyle trial [10].

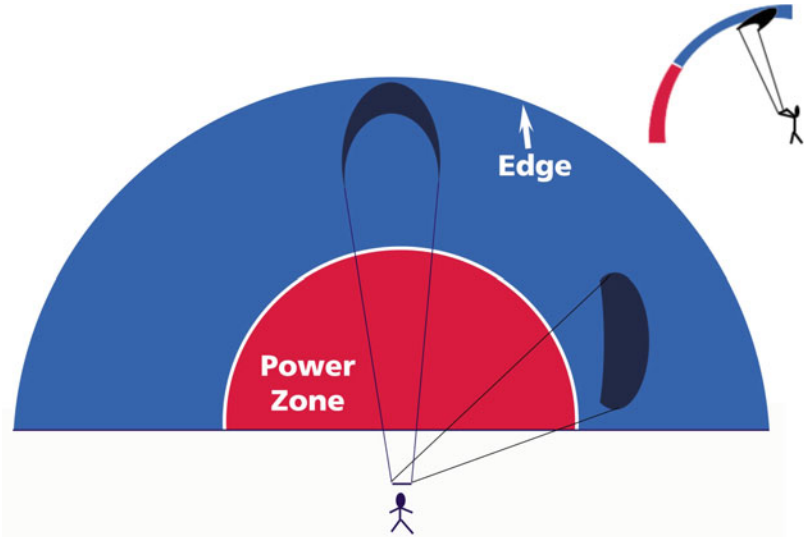

Fig. 15.9 Wind window. The kite always flies in an area of the sky that is shaped like a quarter of a sphere, downwind from the kiter: the wind window. The upwind edge of the wind window is shaped like a semicircle, which passes over the rider's head at an angle of 90° with respect to the direction of the wind. This is a neutral area. The closer the kite is to the center of the wind window, the more the incidence of the wind on the wing approaches 90°, and the greater the power generated by the kite, the maximum power being obtained when the kite is at the center of the window exactly downwind of the rider, the area known as the power zone

15.3.1 Unhooked Maneuvers

To perform particular acrobatic freestyle tricks, the kiter can unhook the chicken loop while remaining temporarily attached to the kite only by his grip on the bar. These maneuvers require an intense effort on the part of the kiter to maintain his grip on the bar, steer the kite, and perform the desired tricks at the same time, all placing the shoulders and elbows under particular strain. In addition, by unhooking the kite from the harness, the point where the wind force acts on the kiter moves with respect to his center of gravity. As a consequence, an unhooked kiter is unable to lean back and counteract the pull of the kiter by applying more pressure on the back edge of the board, but tends to be dragged downwind by the kite. For this reason, in order to maintain sufficient tension on the lines to steer the kite, the athlete must increase the power supplied by flying the kite lower, near the center of the wind window (power zone; Figs. 15.9 and 15.10). This means that during unhooked maneuvers, the traction of the kite has a greater tangential component with respect to the surface of the water making landings during unhooked maneuvers much more demanding and traumatic than hooked performances.

15.4 Acute Injuries

15.4.1 Injury Rates

A review of the literature reveals a wide range of injury rates depending on study design, the different skill levels of the participants, and the discipline practiced [9]. Nickel et al. [11] in their prospective study defined an injury as "any damage to the body that resulted in incapacity to practice or compete normally," finding an overall injury rate of 7 per 1000 h of practice. The risk of injury was 2.5 times higher during competition than during practice, reaching values of 16.6 injuries per 1000 h. Among professional kiters taking part in the World Cup Fuerteventura 2008, Pérez-Turpin et al. [12] found that most of the injuries sustained during competition (66.7 %) caused more than 1 week of inactivity, while only about one third (34.5 %) of those sustained during training required more than 1 week of rest. In the same study, many more injuries were sustained in the discipline of course racing (68.4 %) than in freestyle (31.6 %). In wakestyle, the risk of injury is higher since maneuvers are performed at high speed and often involve various rotations

Fig. 15.10 Rider: Fabio Ingrosso. Unhooked maneuvers. Unhooked maneuvers are practiced by very skilled kiters. Unhooking the kite from the harness allows the freedom of movement necessary to perform more extreme maneuvers. During unhooked maneuvers, the kite is at a lower angle from the; surface of the water it is approximately 45° compared to 60° or more during hooked maneuvers (Photo courtesy of Fabio Ingrosso)

of the body with possible loss of kite and board control [3].

Wegner and Wegener [13] reported significantly more injuries among inexperienced kitesurfers compared to more expert kiters. In addition they described a trend whereby the rate of injuries decreased constantly as skill level increased (from 30.9 to 6.1 injuries/1000 h), but also that expert kiters sustained more serious injuries. It is probable that the technological progress made in equipment manufacturing has modified both the rate and type of injuries over time. In this regard, Kristen et al. [3] in their study on the injuries sustained in the Kitesurf World Cup event in Podersdorf (Austria) between 2002 and 2013 found that the rate of severe injuries during competition decreased over the period studied, while the rate of mild injuries, those which allowed the athletes to continue competing, remained stable.

15.4.2 Most Common Injuries

According to Nickel et al. [11], 77 % of the injuries were mild, i.e., affecting the capacity to train or compete normally but without resulting in absence from practice. Nineteen percent of injuries were classified as medium (causing absence from practice for more than 1 day), three percent were severe (leading to absence from practice for more than 6 weeks), and only one was catastrophic. In the same series, out of 124 injuries, 53.2 % were to the lower limbs, 16.9 % to the upper limbs, 16.1 % to the trunk, and 13.7 % to the head. A similar distribution was found in other studies [8, 14, 15]. Nickel et al. [11] also found the ankle and foot to be the most commonly injured region of the body (28 %; $n=35$), sustaining injuries mainly consisting of sprains of the ankle ligaments but also including fractures of the ankle and the fifth metatarsal bone. Knee injuries were also common (12.9 %; $n=16$) and were mainly represented by ACL, PCL and medial collateral ligament tears. Thoracic injuries included contusions and rib fractures, while the most common type of injuries to the head were lacerations, although contusions associated with concussion and with nasal hematoma were also noted. Severe maxillofacial trauma and eardrum, tooth, and eye injuries have been reported in other studies [14, 16]. More recently, Pérez-Turpin et al. [12] examined an elite group of kitesurfers finding that the ankle joint was affected in 61 % of cases followed by the foot (13 %) and knee (11 %), while only five percent of injuries were to the upper extremities and trunk.

15.4.3 Dynamics of the Most Common Injuries

Errors during maneuvers and tricks are the most common cause of injuries with the lower limbs

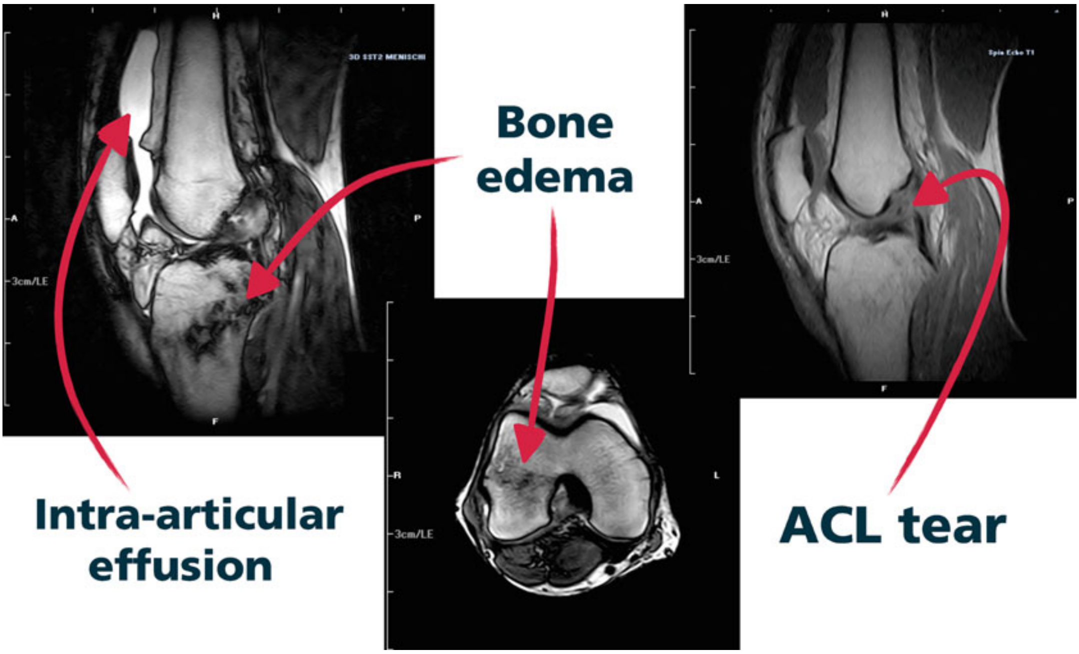

Fig. 15.11 Magnetic resonance imaging (MRI) of an injuied freestyler knee as a consequence of a poor landing from an aerial maneuver (*kiteloop*). Injuries consisted of the anterior cruciate ligament rupture, extensive bone edema, and intra-articular effusion

being particularly affected due to falls or poor landings from jumps performed intentionally [8, 11, 14, 15, 17]. Injuries with this dynamic mainly cause lesions to the knee (Fig. 15.11) and ankle [11, 17]. In particular, the high rate of foot and ankle injuries is due to the instability of the attachment between the foot and the board, a factor associated with the use of the foot straps. Sprains to the foot and ankle most commonly involve excessive supination with inversion and extreme plantar flexion which can cause lesions of varying degrees to the ligaments, dislocation, and frequently also fractures [15] (Fig. 15.12).

Knee sprains occur due to a rotation of the femur with respect to the tibia, the latter being in a fixed position on the board. This trauma pattern causes tears or sprains of the cruciate and collateral ligaments and meniscal lesions [3, 15]. Among more advanced athletes, the use of bindings which stabilize the connection between the foot and the board probably reduces the risk of injuries to feet and ankles, but probably also

Fig. 15.12 Radiography showing the fracture of the fibula (*circle*) sustained following a poor landing from a jump during a session of freestyle kiteboarding

Fig. 15.13 Rider: Fabio Ingrosso. Complex unhooked jump including a handle pass in flight. The only element attaching the athlete to the kite (apart from a safety leash) is his grip on the boom. Handle passes expose the athlete to the risk of shoulder lesions in the event of an error. Landing from jumps also puts the rider at risk of lower limb injuries. In this case, the use of bindings stabilizes the foot and the ankle, while the knee remains exposed to the risk of sprains, due to rotation of the femur with respect to the fixed tibia (Photo courtesy of Fabio Ingrosso)

leads to a greater potential for injury to knees due to the fixed connection between the lower leg and the board [3]. Technical skills may also play a protective role, allowing a more stable body position upon landing and reducing the risk of injury accordingly [8]. The high scoring of handle pass maneuvers (in which the handlebar is passed from one hand to the other behind the back; Fig. 15.13) during competitions has led to a significant increase in the incidence of shoulder lesions in high-level athletes [3]. During this type of maneuver, the traction load, often brusque and exerted on the arm while in an elevated position (especially if the maneuver is poorly executed), may lead to a number of injuries, particularly dislocation or subluxation of the shoulder.

Overall, lesions to the cervical spine and ribs seem to have decreased progressively over time [3].

Environmental factors (e.g., gusty winds, choppy or shallow water) and equipment (e.g., one foot slipping out of the strap, a blow from a fin, an injury to the chest caused by the harness compression, a kite continuing to pull after falling) may contribute to the occurrence of incidents and can influence the extent of injuries in 74 % of cases [8]. An association between injuries and greater wind speed [17] is unsurprising. A certain correlation between injuries and wave height has also been noted while injuries appear to be less frequent in shallow water [14] (Fig. 15.14). Cases of fractures to the ribs, humerus or ankle due to impact with the board [19] have also been reported, as well as lacerations caused by the sharp lines of the kite [11].

15.4.4 Catastrophic Injuries and Fatalities

Iossi [18] roughly estimated an annual US fatality rate as being in the range of 6–12 fatalities out of 100,000 riders in 2005. He also examined a total number of 52 reported kiteboarding fatalities worldwide through July 2006 and found that most fatalities (65 %) involved kitesurfers with more than 3 years of experience and that older riders in their late 30s and 40s seemed to be at the highest risk (the average age was 39 years). The majority of fatalities (54 %) occurred during launching and landing near or onshore, and riders were lofted in 67 % of cases. Indeed, loss of kite control and the inability of the kitesurfer to

Fig. 15.14 Potentially dangerous environmental conditions. An expert kiter wave riding with side offshore wind close to a rocky shore in Cape Verde (Photo: Claudio Marosa)

release the kite on the beach or near the shore has been described as the main risk factor for severe injuries and fatalities by different authors [3, 16].

Fatal polytrauma, severe wounds and head trauma occurring due to this dynamic [11, 16, 17, 19] have been reported as a consequence of falls from a height or collision against obstacles such as sea walls, dams, poles or parked cars. Gusty winds related to squalls or wind shadow from shore obstructions have been reported as a factor in 67 % of fatalities, and insufficient distance or buffer from hard objects resulted in 65 % of cases [18]. Equipment breakage or unwise equipment choices such as excessive kite size also play a role in the dynamic of catastrophic events [17]. Physicians involved in treating victims of kiteboarding incidents should always consider that loss of control during kitesurfing may cause high-energy trauma and severe injuries. In this regard, Spanjersberg et al. [16] described the case of a kiter lifted out of the water who was thrown approximately 20 m through the air before colliding with a billboard. Apparently unhurt, he was hospitalized as a precaution and kept under observation and developed neurological symptoms 30 min after admission. A CT scan showed traumatic bilateral internal carotid artery dissection and associated left frontal lobe ischemia which resulted in severe and persistent behavioral problems.

Kitesurfers are well aware of the risks associated with collision with another kitesurfer, windsurfer or watercraft. The equipment can be damaged by the impact making the kite impossible to control. A kite incidentally lost by an athlete during unhooked maneuvers or quick-released for safety reasons can create extremely dangerous situations if it becomes tangled in the wing or in the lines of another kitesurfer since both kites become out of control and generate a huge amount of power. With this dynamic, Nickel et al. [11] reported the case of a 25-year-old female kitesurfer who sustained a fatal rupture of the liver parenchyma after being thrown against a jetty by her kite which had become tangled in the wing released unintentionally by another kitesurfer during a jump.

Another perilous situation is equipment breakage far from shore making sailing impossible and forcing kiters to remain in the water for long periods of time. Although many incidents occur on the beach (20 %) or at less than 50 m from the shore (26 %), the majority (54 %) occur farther away. [17]. Especially in certain environmental conditions, the kiter can be dragged out to sea by wind or currents further complicating the situation. Exadactylos et al. [19] described 30 rescue missions involving kitesurfers located too far from the coast and unable to return to shore; 17 % of these situations were injury-related while the others were caused by loss of kite control due to excessively strong winds or the impossibility of relaunching the kite offshore due to low wind. None of the kiters involved were wearing a life-jacket. Two of the athletes suffered hypothermia and exhaustion while a third reported severe exhaustion. Ziegler et al. [20] reported the case of a 52-year-old kitesurfer who lost control of the kite during a lesson. Unable to free himself from the kite due to the lines becoming tangled in the harness hook, he was dragged through the water and subsequently drowned.

15.5 Overuse Injuries

Among 38 elite competitors, Pérez-Turpin et al. [12] reported many more acute than overuse injuries accounting for 76.3 % and 23.7 % of injuries respectively. Nevertheless, this percentage could not be generalized to the kiteboarding population as a whole due to the limited size of the sample, the elite subgroup of kitesurfers examined, and the retrospective nature of the questionnaire employed. Kiteboarders are probably at high risk of overuse injuries, in particular to the lumbar spine due to extreme loads in compression and bending [21], and to the knees and ankles due to the prevalently isometric nature of effort required in kiteboarding and repetitive microtrauma. In 2002, Kristen and Kröner [22] described the stress fracture of the ribs, in particular the 7th to the 9th, as an overuse injury typical of kitesurfing caused by the elevated pressure exerted by the trapeze due to the traction generated by the kite in combination with rotational forces. The incidence of this type of lesion has decreased significantly thanks to the advances in trapeze construction technology [3].

The cervical spine is particularly prone to overloading in beginners who must constantly look up to maintain visual control of the kite in flight, while in most advanced riders, it is prone to violent whiplash injuries sustained in falls during high-speed maneuvers. The lumbar spine, on the other hand, is exposed to high flexion-rotation loads; therefore, any instability or degenerative changes in the spine must be considered a contraindication to pursuing this type of sporting activity [3].

Finally, Valsecchi [23], using accelerometers, found that whole body vibrations associated with kitesurfing crossing reach thresholds prescribed by the European Directive for Workers (2002/44/EC) within 15 min mainly correlated with gliding speed. Therefore, it is possible that repeated exposure to long sessions of this sport could cause vibration-induced damage to the body, particularly inflammation and degeneration of the joints and degenerative conditions affecting the spine and the lower limbs.

15.6 Prevention

Power kites can rapidly generate significant levels of energy. It is therefore advisable that kitesports should be learned gradually in suitable locations under the guidance of a qualified and experienced instructor. Although injuries can be caused by factors beyond the kiter's control, the risks can be minimized by adopting a number of precautions – the use of equipment in good condition that is fitted with the necessary safety systems; an appropriate level of physical fitness and training which permits the kiter adequate control over the kite; and careful evaluation of weather conditions and locations where the sport can be practiced safely.

15.6.1 Equipment

Technological advances in kiteboarding equipment mean today's kitesurfers are much less likely to find themselves at the mercy of an out-of-control kite. Total-depower kites came into use around 2005 allowing the kiter to virtually eliminate the pull of the kite simply by letting go of the bar. Kite performance has also generally improved in relation to size, making them smaller and less dangerous in the event of loss of control, and 95 % of kitesurfers use these safer and more modern kites [24]. In addition, all modern kites have a chicken loop fitted with a quick-release system, a safety device that was not used by all kitesurfers when the sport was in its infancy [11]. In order to break free from any possible catch lines, safety equipment should include a kite line cutter which can be fixed on the trapeze or the shock protection vest; specially designed “hook” models are available, to prevent any possible injury to the kiter [3, 20]. The use of a kite leash is highly recommended due to the potential dangers associated with a loose wing either during unhooked maneuvers or as a consequence of the use of a quick-release system. The use of an elastic board leash, meanwhile, is more controversial. While it can prevent the board hitting or injuring other water users such as swimmers or surfers, it can also cause the board to catapult back against the kiter causing injuries to the head or the neck, the most exposed parts of the body when the athlete is floating in the water after coming off the board. For these reasons, the use of a helmet, while always recommended, is mandatory when a board leash is used [11]. It is crucial that equipment and safety systems whose efficiency can be affected by sand and salt water are properly maintained [3]. To prevent lumbar spine overload, a seat-type harness is the best choice for those suffering from back problems since this kind of harness spreads the traction forces to the entire pelvic area, legs, and hips, rather than to the lumbar region only [25].

15.6.2 Wind Turbulence

Kiters should avoid onshore and excessively gusty winds either from squalls or from land wind shadow effects. Being a sport which is practiced close to the shore, it is always important to consider the fact that large obstacles (trees, buildings, ships, and similar objects) on the coast or in the immediate vicinity can alter the flow of the wind and create dangerous turbulence. The turbulence is proportional to the speed of the wind and extends both down- and upwind of the obstacle for a distance of up to seven times and three times its height, respectively [25]. The wind passing over such obstacles moves upwards creating upward currents that can literally lift nearby kitesurfers into the air while the wind that passes between two obstacles can accelerate due to the Venturi effect. For these reasons, it is always good practice to avoid unnecessary lingering on the shore especially near obstacles. Kiters should maintain a safety distance of at least 130 m downwind and 50 m laterally from any obstacles, even more-so in excessively gusty conditions [22]. It is also important to bear in mind that the wind may change strength and direction at any time and can be unpredictable even for very skilled kiters.

15.6.3 Rescue

In the event of equipment breakage, a kite may become impossible to fly. In this case, the board does not permit the kiter to remain afloat. Indeed in kitesurfing, the rider is kept afloat due to the hydrodynamic effect generated by the board gliding over the water and not by the float of the board itself. Most available kiteboards actually have little float and do not allow the kiter to stand upright on the board while stationary. For these reasons, in the event of an incident, the kite should not be abandoned for any reason. Since it is highly visible, it allows the kiter to be located by rescue personnel. Inflatable kites also give the kiter something on which to cling to stay afloat. Inflatable kites also allow “self rescue”, a technique which involves the kiter wrapping the lines neatly around the bar and taking control of the kite by grabbing both wing tips. Alternatively with larger kites, athletes can lie on one wing tip and grab the other side using the kite as a sail to drag themselves back to shore [26]. The greatest risks for kitesurfers who remain in water for any length of time are hypothermia and exhaustion [19]. When equipment failure occurs far from shore or in strong winds or currents sweeping out to sea, it is crucial that that the kiter is rescued by crews with the proper equipment and knowledge as quickly as possible. For these reasons, kitesurfing should always be practiced in locations with available rescue facilities or together with other kitesurfers in order to provide rescue if necessary.

15.6.4 Clothing

Head injuries may be caused by hard impact with a wave, the board or obstacles of various kinds. Due to the considerable energy involved, the effects of impact with water must not be underestimated, and use of a protective helmet is recommended to avoid lacerations, concussion and brain damage. Helmets should be especially designed for water sports, manufactured in light and impact-resistant plastic with a closed, cell-foam lining that does not absorb water. The kiter should be able to remove it unaided, and a well-designed model should allow good peripheral vision especially when looking up, and should not interfere with hearing [19, 25]. Helmets are still greatly underused despite being obligatory in many countries; indeed only 40 % of kitesurfers use helmets and impact vests. [8]. Impact vests use anti-shock technology to minimize chest trauma, but generally provide a very low degree of buoyancy and cannot be considered flotation devices. It is critical to understand the difference between the different types of available flotation devices. Life jackets allow a person to be kept face up in water in the event s/he becomes unconscious and offer a flotation of 150 N or more. They are quite bulky however, and many kiters argue that they restrict movement. Buoyancy aids provide much lower floatation, at least 50 N, but their design permits much greater movement, and they are more suitable for swimming [25]. Conformity to the minimum standard of ISO 12402–5 (level 50) is required by *World Sailing* for those competitions in which personal buoyancy is prescribed [5, 27]. Some flotation devices are specifically designed to enable the user to wear a kitesurfing harness. Models that are known as combo jackets integrate a waist harness with a flotation vest leading to the advantage of kiters wearing a floatation device every time they use the harness without interference between the two outfits [25].

Garments in neoprene provide effective protection against hypothermia. T-shirts available in various weights and thicknesses are comfortable even in very warm climates, while wetsuits which cover the whole body including neck and limbs also offer protection against sunburn and stings from jellyfish and other marine species. The need to wear gloves and socks depends on where kiters intend to practice. Their use is recommended when there is the potential contact with rocks or rough seabed or in areas with sea urchins or coral. Given that exposure of skin and eyes to the sun is a risk factor for skin cancer and melanoma, the use of protective clothing (including sunglasses) and creams or lotions that offer a high sun protection factor is recommended in kiteboarding as well as other water sports [28].

15.6.5 Physical Preparation

Sixty percent of kiters believe kitesurfing can be practiced with little physical training, and 80 % believe their own physical fitness to be adequate [15]. This suggests that the level of physical conditions of these individuals could actually be quite low, whereas kiteboarding actually requires a variety of skills – strength, coordination, speed, flexibility, and endurance – making a medium to high level of physical training desirable for those wishing to practice the sport. This is especially important for those who wish to compete. The distance travelled in a certain interval of time increases as aerobic fitness levels do [6]. That is an important factor to be considered in the discipline of course racing. Fatigue and tiredness may increase the risk of incidents1 [8, 15], therefore a specific physical preparation program is an important factor in injury prevention. Proper training regimes involve high volumes of work per week including practice in water, endurance and strength training. Exercises for proprioception are particularly useful in preventing injuries, core stability and articular mobilization [9]. Good muscular stability of the shoulder is vital for those athletes wishing to attempt freestyle maneuvers involving "handle passes," in order to reduce the risks of dislocation and subluxation of the shoulder [3]. Warming up before any session and regular stretching also reduces the risk of injury [8].

Fig. 15.15 Snowkiting with freestyle skis. Rider: Benoit Miquel. Location: Col du Lautaret, France (Photo: Ramon Schoenmaker; photo courtesy of Flysurfer)

15.7 Snowkiting

Snowkiting is a kitesport which is practiced on snow using freestyle skis or snowboards (Figs. 15.15 and 15.16) and the same power kites (both inflatable and foil kites) used in kiteboarding. The traction of the kite allows it to be practiced not only in descent, but also in the absence of a slope or even uphill. Gentle hillsides are generally preferred since the wind may become turbulent when passing over mountaintops while steeper slopes may alter the flow of wind causing the kite to behave erratically. This extreme sport is becoming more and more popular all around the world especially in windy locations where snowfalls are plentiful. Since maximum speeds reached are over 100 km/h in jumping heights that can exceed 10 m, there is the risk of serious injuries while snowkiting.

15.8 Snowkiting Injuries

In their prospective study of 80 snowkiters in which they defined an injury as “any physical complaint, irrespective of the need for medical attention or time lost from sports activities”, Moroder et al. [29] estimated an injury rate of 8.4/1000 h with a small difference between practice (8.5/1000) and competition (7.5/1000). The authors also classified injuries based on the extent of impairment from sport participation. They were “mild” if symptoms allowed normal sports participation; “moderate” when these led to par-

Fig. 15.16 Snowkiting with a snowboard. Rider: Laurent Guyot. Location: Col du Lautaret, France (Photo: Ramon Schoenmaker; photo courtesy of Flysurfer)

tial restriction from the usual level of performance; "severe" if they led to a temporary total restriction from sports participation; and "catastrophic" when resulting in permanent disability or death. They found prevalently mild injuries (60.6 %; *n* = 20), followed by moderate (21.2 %; *n* = 7) and severe ones (18.2 %; *n* = 6), while no catastrophic injuries were reported.

Although beginners were subject to a significantly higher risk of incidents (20.8 incidents/1000 h) compared to experts (5.1/1000 h), their injuries were predominantly minor while expert riders tended to suffer moderate or severe injuries. This is probably due to the fact that expert snowkiters practice the sport in even more demanding wind conditions and perform particularly extreme maneuvers. It is interesting to note that the riders who practice snowkiting using a snowboard are much more prone to injury than those using skis (11.7 vs. 4.1 injuries per 1000 h of exposure), a figure that is similar to that which emerges from comparative studies between skiing and snowboarding in general [30–32]. However, this result should be further investigated in more specific studies since the pulling force of the kite is a very important additional variable to the dynamic of incidents in snowkiting and can modify the way similar equipment affects injuries. Moroder et al. [29] found many injuries to the back (30.3 %; *n* = 10, particularly contusions and abrasions: 70 %); to the knees (24.2 %; *n* = 8) including sprains and anterior cruciate ligament rupture; and to shoulders (21.2 %; *n* = 7) including dislocations and collarbone fracture. Compared to kitesurfing, knees were affected at a similar rate, while injuries to the ankle and feet were much less frequent. The use of ski or snowboard boots stabilizes and protects these areas of the body, as opposed to kiteboarding straps which conversely can promote injuries. Shoulders, however, seem much more prone to injury in snowkiting than in kiteboarding.

Head injuries were a low percentage (21.2 %; *n* = 7), compared to skiing and snowboarding, probably because almost all participants wore a helmet when snowkiting [33]. Multiple causes may contribute to incidents: rider errors were the most commonly reported cause (75.8 %) followed by gusts of wind (36.4 %) and poor snow conditions (27.3 %) such as scarce snow coverage, frozen snow surface or powder snow (so deep that it concealed dangerous obstacles from view). Collisions with other snowkiters were another reported cause of injuries. More injuries (48.5 %) occurred during maneuvers such as high jumps and changes of direction than during simple cruising (30.3 %). Although it is obviously dangerous to practice snowkiting in strong winds, practicing this sport in lower but gusty winds may also place kiters at the risk of injury. Finally, fatigue appears to be a risk factor since the majority (84.9 %) of injuries occurred between the middle and the end of the session [29].

15.9 Prevention

Since novices run a higher risk of injury in snowkiting and rider errors are the most common cause, beginners should be introduced to snowkiting by professional instructors. The fact that snowkiting is practiced on hard ground makes kiters more inclined to use protective equipment. In fact, in the series by Moroder et al. [29], 92.5 % used a helmet, 51.3 % used a spine protector, and 20 % used shoulder protectors. Although almost all participants (93.9 %) had a quick-release system mounted on their kite at the moment of injury, only one third were able to deploy it when the incident occurred due to the speed of events or to loss of control over the situation. In certain cases, however, the quick-release system may itself be responsible for incidents or dangerous situations. The authors reported the case of a kiter who had a tooth knocked out by the bar following spontaneous release of the system. Another snowkiter was knocked unconscious following a bad landing from a jump making him unable to activate his quick-release system, and he was dragged along the ground [29]. It is therefore important that beginners are trained to use safety systems before using the kite under power. Since fatigue plays a role in injury occurrence, athletic preparation is an important prevention strategy. Unfortunately, only 42.5 % of snowkiters undertake any kind of physical preparation [29]. Moreover, most of those who undergo some forms of physical conditioning practice strength (26.3 %) or endurance (35 %) training while only a somewhat small percentage (22.5 %) perform exercises to improve balance and flexibility [29]. A proper physical conditioning program for snowkiting, however, should include all of these components, combining strength and endurance training with exercises to improve coordination, proprioception and joint mobility.

Conclusions

Due to the growing number of kitesport participants, physicians should be familiar with the patterns of the most commonly sustained injuries including the possibility of serious injuries resulting from high-energy trauma. Prevention strategies should include the training of beginners by professional instructors regarding wind and weather before practicing these sports; a careful choice of locations; and the use of proper equipment including the necessary safety systems combined with a specific physical training regime. Future medical research into kitesports is needed. It should include overuse injuries and illnesses and should be taken forward by way of well-designed studies dealing separately with amateurs and elite kiters taking into account the differences between disciplines as well as any new developments in protective equipment, clothing and technology.

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References

1. Needham J. Science and Civilisation in China. Cambridge University Press. Part 2. Mechanical Engineering; Vol. 4, Physics and Physical Technology. 1965; 2, 27:589.
2. ISAF Kiteboarding Format Trials. Technical report. Events committee – May 2012 item: 8(b) Santander. p. 1–33.
3. Kristen K, Syré S, Humenberger M. Kitesurfen – sportmedizinische Aspekte, Risikofaktoren und Verletzungen. OUP. 2014;6:306–11. doi:10.3238/oup.2014.0306–0311.
4. Kitesurfing styles. In: Kitesurfing handbook. Available from: http://kitesurfing-handbook.peterskiteboarding.com/kitesurfing-styles. Accessed Jan 2014.
5. International Ika Formula Kite Class Rules. 2015. http://www.sailing.org/tools/documents/FK2015CR190315-[18659].pdf. Accessed July 2015.
6. Vercruyssen F, Blin N, L'Huillier D. Assessment of the physiological demand in kitesurfing. Eur J Appl Physiol. 2009;105:103–9.
7. Spurway NC. Hiking physiology and the "quasi-isometric" concept. J Sports Sci. 2007;25:1081–93.
8. Lundgren L, Brorsson S, Hilliges M, Osvalder A. Sport performance and perceived musculoskeletal stress, pain and discomfort in kitesurfing. Int J Perform Anal Sport. 2011;11(1):142–58.
9. Bourgois JG, Boone J, Callewaert M, Tipton MJ, Tallir IB. Biomechanical and physiological demands of kitesurfing and epidemiology of injury among kitesurfers. Sports Med. 2014;44(1):55–66.
10. Camps A, Vercruyssen F, Brisswalter J. Variation in heart rate and blood lactate concentration in freestyle kytesurfing. J Sports Med Phys Fitness. 2011;51(2):313–21.
11. Nickel C, Zernial O, Musahl V, Hansen U, Zantop T, Petersen W. A prospective study of kiteboarding injuries. Am J Sports Med. 2004;32(4):921–7.
12. Pérez-Turpin J, Cortell-Tormo J, Suarez-Llorca C, Jove-Tossi M, Andreu-Cabrera E, Carrasco-Embuena V. Lesiones en kitesurfistas de élite masculinos. Injuries in elite male kitesurfers. Retos Nuevas tendencias en Educación Fisica, Deporte y Recreación. 2011;20:30–2.
13. Wegner M, Wegener F. The relationship between sensation seeking and tendency to suffer injuries among kite surfers. Zeitschrift Fur Sportpsychologie. 2012;19(3):122–30.
14. Kwiatkowski A. Unfall und Präventionsmechanismen beim Kitesurfen unter Wettkampf- und Freitzeitbedingungen. Hamburg: Universität Hamburg; 2009.
15. Berneira O, Domingues R, Medeiros A, Vaghetti O. Incidência e caracterìsticas de lesões em practicantes de kitesurf. The Revista Brasileira de Cineantropometria e Desempenho Humano. 2011;13(3):195–201.
16. Spanjersberg WR, Schipper IB. Kitesurfing: when fun turns to trauma-the dangers of a new extreme sport. J Trauma. 2007;63(3):76–80.
17. Petersen W, Nickel C, Zantop T, Zernial O. Verletzungen beim Kitesurfen. Orthopade. 2005;34:419–25.
18. Iossi R. Fatality analysis, 2000 to July 2006, Florida kitesurfing Association. http://fksa.org/showthread.phpt=4125.
19. Exadaktylos AK, Sclabas GM, Blake I, Swemmer K, McCormick G, Erasmus P. The kick with the kite: an analysis of kite surfing related off shore rescue missions in Cape Town, South Africa. Br J Sports Med. 2005;39(5):26.
20. Ziegler M, Lockemann U, Püschel K. Fatal accident during kite surfing lesson. Rechtsmedizin. 2009;19(3):162–4.
21. Kristen K, Kröner A. Kiteboarding—Surfen mit Lenkdrachen: Präsentation und Risikoabschätzung

einer neuen Trendsportart. Sportorthopädie Sporttraumatologie. 2001;17:253–9.
22. Kristen KH, Kröner A. Orthopädische Checkliste: Kitesurfing/Kiteboarding – Surfen mit Lenkdrachen. Sportortho- pädie – Sporttraumatologie. 2002;18: 204–5.
23. Valsecchi M. Whole body vibration in kitesurfing. Milano: Politecnico di Milano; 2010.
24. Pikora TJ, Braham R, Hill C, Mills C. Wet and wild: results from a pilot study assessing injuries among recreational water users in Western Australia. Int J Inj Contr Saf Promot. 2011;18(2):119–26.
25. Iko Kiteboarding. Iko instructor manual. Iko, Cabarete: Puerto Plata Dominican Republic; 2011.
26. Iko Kiteboarding. Self rescue & pack down. Iko, Cabarete: Puerto Plata Dominican Republic; 2010.
27. International IKA twin tip racing class rules. 2013. http://www.sailing.org/tools/documents/TTR2014CR011213-[16230].pdf. Accessed July 2015.
28. Buchholz S, Rudan G. A professional kitesurfer with multiple liver lesions. Med. J Aust. 2007;187(10): 590–1.
29. Moroder P, Runer A, Hoffelner T, Frick N, Resch H, Tuber M. A prospective study of snowkiting injuries. Am J Sports Med 2011;39(7):1534–40. doi: 10.1177/0363546511398214.
30. Sakamoto Y, Sakuraba K. Snowboarding and ski boarding injuries in Niigata. Am J Sports Med. 2008;36(5):943–8.
31. Made C, Elmqvist LG. A 10-year study of snowboard injuries in Lapland Sweden. Scand J Med Sci Sports. 2004;14(2):128–33.
32. Dohjima T, Sumi Y, Ohno T, Sumi H, Shimizu K. The dangers of snowboarding: a 9- year prospective comparison of snowboarding and skiing injuries. Acta Orthop Scand. 2001;72(6):657–60.
33. Sulheim S, Holme I, Ekeland A, Bahr R. Helmet use and risk of head injuries in alpine skiers and snowboarders. JAMA. 2006;295(8):919–24.

Skydiving Injuries

16

Trevor J. Mills

16.1 Introduction

According to the United States Parachute Association (USPA), approximately 3 million skydives were made in 2013 at 220 different drop zones, and the USPA currently lists a membership of more than 34,000 [1]. Over time, the USPA has carefully tracked fatality statistics, and there are a handful of research studies estimating injury rates related to sport skydiving in the United States. This chapter summarizes the current literature and statistic, to detail the mortality and incidence of injuries encountered in the sport of skydiving.

16.2 Skydiving

16.2.1 Historical Perspective

The earliest account of skydiving comes from China in the fourteenth century. Shortly after the invention of the umbrella, there are reports of attempts being made to use it as a rigid parachute. Leonardo da Vinci designed a device resembling a parachute in the late fifteenth century, while the first account of a successful drop was from the tower of the Montpellier Observatory in 1783, accomplished using a canvas device measuring 14 feet in diameter. The first successful drop with a collapsible parachute was by an American balloonist in 1885, and the parachute pack and ripcord came into existence at the turn of the twentieth century. The first jump from a plane was by Grant Morton in 1911, in California, and by 1919, the US army had developed and successfully tested the Type A back pack, with Lt. Harold R. Harris making the first emergency jump from an airplane with a parachute in 1922. Round parachutes predominated for the first half of the century and were replaced in the mid-1970s with the high-performance rectangular parachutes commonly called “squares,” or parawings. The parawing parachute, designed for maximum lift as opposed to maximum drag, was the primary sport parachute in the 1970s. By the late 1970s, the parawing was replaced by the parafoil. The parafoil or ram-air parachute is a deformable airfoil that maintains its profile by trapping air between two rectangular membranes. This parafoil set the scene for the further evolution of high-performance parachutes from the 1980s to today.

Organization of the sport began in 1926 at the National Air Races in Philadelphia, where the first formal “sport jumping” competition was held, and in 1933, the National Aeronautic Association formed the National Parachute Jumpers Association. This evolved into the National Parachute Jumpers-Riggers Inc. and finally became the Parachute Club of America

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(PCA) in 1957. PCA renamed itself the United States Parachute Association (USPA) in 1967, as it remains to this day.

In Europe, the Federation Aeronautique Internationale created an International Parachuting Commission in 1948. The first world event occurred in the country formally known as Yugoslavia in 1951 and included five countries. By 1964, this competition, now known as the world championships, grew to include 31 countries. In 2012, the world championships were held in Dubai, involving 56 countries and thousands of participants.

16.2.2 Styles and Disciplines

Sport skydiving is continually growing in popularity in the United States and worldwide, with many styles and disciplines.

In *formation skydiving* and *vertical formation skydiving,* teams of 4 (4-way), 8 (8-way), 10 (10-way), or 16 (16-way) skydivers perform a designated sequence or series of formations, drawn from an international pool (*dive pool*) [1] (Fig. 16.1).

In *freeflying* and *freestyle,* sequences of freefall moves are scored by judges (Fig. 16.2); in *sky surfing,* sequences are performed with the jumper wearing a board similar to a snowboard.

Speed and correctness of execution of a prescribed sequence of maneuvers are the goals of *freefall style,* while in *accuracy landing* and team accuracy, the aim is to land as closely as possible to the center of a target.

In *canopy piloting,* parachuted flight is judged in terms of speed, distance, and accuracy.

Canopy formation consists of building different formations while under open canopies.

In *speed skydiving,* the aim is to achieve and maintain the highest possible terminal velocity. Thanks to the minimization of drag by streamlining the body, generally in a head-down position, it is possible to achieve speeds of 480 km/h, which are more than double the terminal velocity in the traditional belly-to-earth position (200 km/h) [1].

High-altitude jumps include the two subdisciplines of *HALO* (high altitude – low opening) and *HAHO* (high altitude – high opening), derived from high-altitude military parachuting, and may require supplemental oxygen.

Apart from the aforementioned disciplines, skydivers may take part in special stunts or events and performances, including *night jumps*, *big ways* (large formation jumps), or *stuff jumps,* in which skydivers jump out with an object (Figs. 16.3 and 16.4).

16.3 Review of Literature on Skydiving Injuries and Fatalities

16.3.1 Early Medical Studies

Early studies were primarily conducted by the military and involved older parachute technology (e.g., "round" parachutes). Historically and today, the majority of injury literature comes from military studies. A summary of injury rates in early studies can be seen in Table 16.1. Of particular note from the early studies is the research by Kiel et al. (1965) [2]. This research included over 1 million jumps, from predominantly civilian records, and is the best estimate of mortality associated with the sport in the early period. In regard to sport parachute mortality, the "100 deaths" came about for a variety of reasons, including airplane crashes with parachutist aboard (3), unintentional parachute opening in airplane (2), equipment malfunction or entanglement (26), failure to pull ripcord until too late (34), mid-air collisions (5), water landing (19), hitting fatal objects (train/power lines, etc.) (4), and others (5). The overall mortality rate between 1956 and 1963 was 87 deaths per 1.12 million jumps (there were an additional 13 deaths in 1964, but no report of the number of jumps). Unfortunately, injuries associated with skydiving are not available from this early period.

16.3.2 The "Modern" Era

From the conversion from T-10 rounds and sub-disciplines Para-Commanders to the first

Fig. 16.1 (**a**, **b**) Formation skydiving (Photo: Dario Vecchiato)

ram-air parachutes of the 1970s to the modern high-performance canopies of today, great strides have been made in parachute technology. Likewise, there have been a number of safety improvements. However, modern parachutes also result in a different set of injuries. Prior to 1993, landing fatalities were uncommon. After 1993, landing fatalities increased to account for a third of all skydiving fatalities in the United States. This increase in landing fatalities is attributed to the popularity of a new generation of high-performance parachutes. Combining a high wing load (the ratio of the exit weight of the skydiver to the surface area of the canopy) with a hook turn, high-performance canopies can be unforgiving when mistakes in handling are made. Hook turns account for a high percentage of fatalities in the United

Fig. 16.2 *Freeflying* and *freestyle* are artistic events in which one member of the team wears a camera and films the video to be judged (Photo: Dario Vecchiato)

Fig. 16.3 Stearman biplane barrel roll exit (Photo: Tom Barrows)

States and are essentially a phenomenon affecting experienced jumpers.

Like the early skydiving literature, much of the recent literature comes from the military, and some of the studies involve a variety of types of parachutes. A summary of more modern studies can be found in Table 16.2.

16.4 Skydiving Injuries and Fatalities

16.4.1 Skydiving Injuries

More recently, one study that focuses on civilian or sport jumps and includes one of the few assessments of morbidity is by Barrows et al. [30].

Fig. 16.4 Stuff jump with an inflatable dinghy (Photo courtesy of Dario Vecchiato)

Table 16.1 Early studies [3–11]

Study	Population	Overall rate of injury per 1000 exits	Size	Year	Equipment	Definition of injury
Tobin et al. (1941) [3, 4]	Military	24	4490	1940–1942	Rounds	All injuries (including minor)
Lord and Coutts (1944) [5, 6]	Military	10	>250,000	1941–1945	Rounds	Injuries resulting in loss of one or more days of duty
Essex-Lopresti (1946) [7]	Military	21	2078	1944–1945	28-foot silk	All injuries (including minor)
Kiel (1965–1966) [2, 8, 9]	Military	3.1	1,020,642	1946–1949, 1956–1962, 1962–1964	Not stated	All injuries necessitating loss of time from duty
Hallel and Naggan (1975) [10]	Military	6.26	83,72	Published 1975	Not stated	All injuries treated on the drop zone or presenting late but requiring hospitalization
Rodrigo and Boyd (1979) [11]	Military	3.1	1846	Published 1979	Not stated	Only lumbar injuries included in analysis

The authors report the prevalence and types of injuries incurred over two consecutive years (2000 and 2001), during the entirety of the World Freefall Conventions (WFFC) in the United States.

The overall study population consisted of 8976 skydivers, who logged a total of 117,000 skydives during the study periods.

The authors found an overall injury rate of 17.4 per 10,000 jumps, with a hospital admission rate of 1.8 per 10,000 jumps, and only one fatality [30].

This study details the plethora of potential injuries associated with skydiving, from minor abrasions to life threatening.

The study includes surveillance for injuries and was conducted both at the emergency department of the local hospital designated for medical care in the event of injury during WFFC and at the First Aid Station on the drop zone.

Table 16.2 Modern era [12–29]

Study	Population	Overall rate of injury per 1000 exits	Size	Year	Equipment	Definition of injury
Petras and Hoffman (1983) [12]	Military	6.8	90,000	1981	T-10	Injuries presenting to the emergency department
Pirson and Verbiest (1985) [13]	Military	5	201,977	1974–1983	665 and 672 non-steerable	All injuries, excluding contusions and abrasions
Ellitsgaard (1987) [14, 15]	Civilian	1.4	110,000	1979–1983	Both round and ram-air	All injuries, including contusions and sprains
Amamilo et al. (1987) [16]	Civilian	3.6	9211	1983–1984	Not stated	All injuries, including minor injuries
Steinberg (1988) [17]	Civilian	1.4	193,611	1981–1985	Both round and ram-air	All injuries reported by survey of local drop zones
Baldwin (1988) [18]	Military	0–11	3246	1981–1986	Round AP 28S-17 and rectangular MT-1X	All injuries, including sprains or injuries resulting in loss of duty time
Lowdon (1989) [19]	Military	2.2	51,828	Published 1989	Not stated	Injuries, except minor injuries
Farrow (1992) [20]	Military	7.1	8886	1987–1988	T-10	All injuries requiring evacuation from drop zone, withdrawal from exercise, restriction of duty, or hospitalization
Bagian (1992) [21]	Military	0.589–10.359	8706	1988–1990	Rounds: P-78 standard porosity vs. SET-10 low porosity	Contusions, sprains, and fractures listed
Kragh et al. (1996) [22]	Military	22	7948	Published 1996	Not stated	Any injuries resulting in a duty restriction
Ekeland (1997) [23]	Military	11.3	4499	1970, 1974–1988	Not stated	Includes minor injuries
Craig and Morgan (1997) [24]	Military	8	200,571	1993–1994	Not stated	Any injury requiring emergency care including contusions
Dawson et al. (1998) [25]	Civilian	1.2	>14,000	1994	Not stated	Injuries presenting to the emergency department, including soft tissue injuries
Bar-Dayan (1998) [26]	Military	8.9	43,542	Published 1998	T-10	Overall rate includes minor injuries
Craig et al. (1999) [27]	Military	24.6	4754	1996	T-10	All injuries including contusions
Craig and Lee (2000) [28]	Military	8.1	242,949	1994–1996	Not stated	Any injury that occurred from the time of boarding the aircraft until the soldier left the drop zone
Schumacher et al. (2000) [29]	Military	1.5–4.5	13,782	1994–1997	T-10C with and without parachute ankle brace	Only ankle injuries, including contusions

At both sites, the emergency medicine staff completed a data form with the patient's age, sex, chief complaint, treatment, and disposition.

The First Aid Station at the WFFC reported treating 204 patients.

Among the complaints suffered by those presenting to the First Aid Station were minor injuries including abrasions, accounting for 22.2 % ($n=45$) of injuries, lacerations (14.9 %; $n=30$), and blisters (9.9 %; $n=20$). Potentially more serious injuries, including ligamentous injuries, fractures, and significant blunt trauma, were recorded by their anatomic location; they were mainly represented by extremity injuries, which accounted for 22.2 % of the total ($n=45$), followed by shoulder injuries (3 %; $n=6$ of which 4 dislocated), head injuries (2.5 %; $n=5$), injuries to the face (2 %; $n=4$), neck injuries (1.5 %; $n=3$), and back injuries (1.0 %; $n=2$).

Other reported injuries included burns (2 %; $n=4$), eye injuries (1.5 %; $n=3$), sunburn (1.5 %; $n=3$), bruises (1.5 %; $n=3$), headache (1.5 %; $n=3$), sore throats or other illnesses (1.5 %; $n=3$), dehydration (1.0 %; $n=2$), insect bites (1.0 %; $n=2$), and one case each (0.5 %) of the following conditions: cast needing extra padding, chest trauma, "hangover," cellulitis, dog bites, bee stings, muscle strains, clavicle fractures, and poison ivy rashes. Nine (4.5 %) patients suffered indeterminate injuries that were unclear as reported on the data sheets.

Significant injuries, transferred to the emergency department for further evaluation, represented 34 % of the total [30]. Most of the injuries evaluated in the emergency department were to the extremities (47.1 %): 45.5 % of these were fractures, the vast majority (81.8 %) to the lower limbs [30]. The other injuries were distributed as follows: 17.1 % to the back (including three cases of fractures), 8.6 % to the neck (including two cases of cervical fractures), and 5.7 % to the shoulder. 2.9 % of the patients sustained closed injuries, but none showed any radiological abnormalities. Thirty percent of skydiving injuries evaluated in the emergency department required hospitalization.

16.4.2 Causes of Nonfatal Injuries

The causes of nonfatal injuries have been examined by Westman et al. in their study on 257 nonfatal injuries in Sweden during the period 1999–2003 [31]. Eighty-four percent ($n=216$) of the injury events occurred during parachute flight, 7.3 % during ($n=19$) parachute opening, 10 % (3.8 %) during landing, 2.7 % ($n=7$) during free fall, and 1.9 % ($n=5$) during exit from the aircraft. Most injury events occurred during parachute flight, and resulted in ground impact or collision with an object or a person: 133 were caused by miscalculations during ordinary flight (including low turns, landings off headwind, and miscalculated horizontal leveling for landing), 33 (12.8 %) were due to turbulence, 17 (6.6 %) to miscalculations during hook turns (intentional low turns aimed at gaining landing airspeed), 16 (6.2 %) to reserve fast sink rate, 7 (2.7 %) to strong winds, 6 (2.3 %) to entanglement, and 4 (1.5 %) to parachute traffic disturbance.

Nineteen (7.3 % of the total) injuries took place during parachute opening; all were produced by parachute opening deceleration: in nine cases, the cause was a hard opening and six cases were due to entanglement, while four cases occurred due to unintentional opening of the main parachute. In a typical civilian parachute launch, the athlete is exposed to a deceleration of about 3–5 G [32, 33]. In this regard, Lo Martire et al. [34] recently showed that neck muscle activity during parachute opening shock reaches mean magnitudes of 53–104 % of reference maximum voluntary electrical activity, often exceeding reference activity in the lower posterior neck and upper shoulders.

In the series by Westman et al. [31], ten injuries were sustained during landing as a consequence of ground impact: three athletes were dragged behind the parachute, while seven landed on unsuitable ground.

Seven injuries occurred during free fall: three skydivers suffered shoulder dislocations due to the action of the airstream forces on the arm and four from human collision, due to miscalculation of the free-fall flight.

Fig. 16.5 Miscalculation during landing (Photo: Dario Vecchiato)

Five (1.9 %) athletes collided with the aircraft during exit, due to insufficient separation from it.

In the same series [31], injuries were distributed as follows: 51 % to the lower limbs, represented by fractures, sprains, and contusions affecting the leg, the ankle, and the foot in particular (Fig. 16.4); 18 % to the back, most of which were compression fractures and dislocations; 19 % to the upper arm; 7 % to the head; 3 % to the chest; and 2 % to the abdomen.

A typical nonfatal adverse event after a correct parachute opening is caused by gusts of wind or miscalculation (off headwind, low turn, incorrect horizontal leveling for landing, etc), resulting in a violent landing leading to back and/or lower limb injuries [32] (Figs. 16.5 and 16.6).

As expected, among most important factors affecting injury occurrence are environmental and geographic factors, as well as unfamiliarity with the drop zone which involves the lack of knowledge of local obstacles, windsocks, and traditional landing patterns [30]. In particular, downwind landings may result in landing injury as they produce high rates of horizontal speed which may be dangerous combined with oncoming landing traffic.

Modern equipment has decreased overall morbidity and mortality; however, it has increased the injuries associated with high-speed landings [30], and today most of the injuries are caused by wing parachute pilot errors [31]. Prevention of skydiving injuries, therefore, requires training on wing parachute piloting, for both novices and more experienced skydivers [31].

Fig. 16.6 Injury dynamic, diagnosis, and treatment of spinal, foot, and ankle fractures in an expert 48-year-old male parachutist, who suffered an incident as he prepared to land near a high poolside windbreak (which induced turbulence and caused canopy deflation). The skydiver sustained a D10 vertebral body compression fracture (**a**; *arrow*), which was treated conservatively. To his right leg, he suffered a displaced, comminuted fracture of the distal epiphysis of the tibia and fibula, reduced using plates, screws, and plaster splint (**b**). To his left foot, he suffered a calcaneal fracture, treated using metal fixators and a plaster splint (**c**) (Courtesy of Dr Feletti, own case series)

16.4.3 Fatalities in Skydiving

For data on modern skydiving mortality, the best estimates come from the USPA website [1], which records deaths per year (Table 16.3). It should be noted that this includes approximately 3 million jumps per year in the recent years.

Table 16.3 Fatalities in skydiving [1]

Year	Fatalities per 1000 jumps
2010	.007 (21 total per 3 million jumps)
2011	.008 (25 total per 3.1 million jumps)
2012	.006 (19 total per 3.1 million jumps)
2013	.0008 (24 total per 3.2 million jumps)

To put this in perspective, based on early research between 1956 and 1963, there were .08 deaths per 1000 jumps, or ten times that of the modern era. With an estimated 3.2 million jumps in 2013, the current rate is one fatality per 133,333 skydives.

Along the period 1994 to 2003, Westman and Bjornstig reported a prevalence of fatalities in skydiving of about 0.8 per 100,000 jumps, indicating a lower risk than that of other activities like motorcycle riding [35].

Similarly, according to Rigou et al., out of 246 injury-related deaths in 2010 in France, parachuting-related deaths (two deaths; 0.8 %) resulted to be fewer than those sustained in other extreme sports such as alpinism (29 deaths; 11.7 %), kayaking (12 deaths; 4.9 %), and paragliding (10 deaths; 4 %) [36, 37].

16.4.4 Causes of Fatalities

Massive injuries to the central nervous, respiratory, cardiovascular, musculoskeletal, and urinary systems were reported as causes of death in a review of autopsy findings in Swedish skydiving fatalities, and as expected, more severe injuries were in the anatomic parts which hit the ground first [32, 35].

With regard to the causes of accidents, the International Parachuting Commission of Fédération Aéreonautique Internationale for 2012 reported 53 fatalities: 60 % ($n=31$) involved experts, 20 % ($n=11$) intermediates, and 20 % ($n=11$) students [38].

The most common reported mechanisms of accident were as follows: intentional fast landings (19 %; $n=10$), other landing errors (11 %; $n=6$), no or low main canopy activation (9 %; $n=5$), and no or low cutaway and reserve activation (9 %; $n=5$).

In particular, out of 53 reported fatalities, 74 % ($n=39$) may have been caused by human error on the part of the skydiver, 85 % ($n=39$) occurred with the skydiver having at least one good parachute on his or her back, and 42 % ($n=22$) happened after the successful deployment of the main parachute [38]. Canopy handling and landing skills had a key role in the mechanism of 36 % ($n=19$) of the 53 reported fatal accidents.

Fatal events, therefore, are mainly related to wing parachute piloting skills of skydivers [32].

16.4.5 Contemporary Issues

While high-performance parachutes were introduced in the 1990s, other innovations have also become popular, leading to additional changes in injury pattern. Wingsuits allow skydivers to obtain significant horizontal speed compared to a traditional free fall (Figs. 16.7 and 16.8), or to fly close to the ground or to fixed objects at high speed (proximity flying, Fig. 16.8), while BASE jumping incorporates a "dive" without the use of an airplane. As discussed elsewhere in this book, in early research studies, both of these modalities have unique risks and injury patterns, while the injury and fatality rates seem to be higher than those of traditional skydiving [39, 40].

Fig. 16.7 Wingsuit flying. Red Bull Air Force team members sky diving in wingsuits while training at Kirby Chambliss' ranch near Casa Grande, Arizona, USA. (Photo courtesy of Red Bull Content Pool/Michael Clark)

Fig. 16.8 Proximity flying. Mile Daisher of the Red Bull Air Force Team taking the leap in his wingsuit and BASE rig off a huge cliff in southwestern Utah in the southwestern USA. (Photo courtesy of Red Bull Content Pool/Michael Clark)

Conclusions

In general, it is true to say that modern equipment has contributed to decrease the overall skydiving morbidity and mortality, and as a result, compared to other "extreme" sports, today skydiving has probably a low injury and mortality rate [30, 35–37].

However, modern parachutes also result in different mechanisms of accident and injury patterns, and today wing parachute piloting (along with landing skills) plays a more important role than parachute opening in the mechanism of accidents.

For these reasons, the teaching and training of parachute piloting is probably the most important prevention measure in modern skydiving, for novices and more experienced skydivers alike. A factor which, along with further equipment innovation and regulation of the sport through national and international associations, may help to continue improving safety in this sport.

References

1. United States Parachute Association (USPA). http://www.uspa.org/AboutSkydiving/SkydivingSafety. Accessed 16 Aug 2014.
2. Kiel FW. Parachuting for sport. Study of 100 deaths. JAMA. 1965;194:150–4.
3. Tobin WJ, Ciccone R, Vandover JT, Wohl CS. Parachute injuries. Army Med Bull. 1943;66:202.
4. Tobin WJ, Cohen LJ, Vandover JT. Parachute injuries. JAMA. 1944;125:1182–7.
5. Lord CD, Coutts JW. A study of typical parachute injuries occurring in two hundred and fifty thousand jumps at the parachute school. J Bone Joint Surg. 1944;26:547–57.
6. Lord CD, Coutts JW. Typical parachute injuries. JAMA. 1944;125:1182–7.
7. Essex-Lopresti P. The hazards of parachuting. Br J Surg. 1946;34:1–13.
8. Kiel FW. Hazards of military parachuting. Mil Med. 1965;130:512–21.
9. Kiel FW. Survey of military sport parachuting deaths. Aerospace Med. 1975;36:360–2.
10. Hallel T, Naggan L. Parachuting injuries: a retrospective study of 83,718 jumps. J Trauma. 1975;15:14–9.
11. Rodrigo JJ, Boyd RE. Lumbar spine injuries in military parachute jumpers. Phys Sportsmed. 1979;7:123–33.
12. Petras AF, Hoffman EP. Roentgenographic skeletal injury patterns in parachute jumping. Am J Sports Med. 1983;11:325–8.
13. Pirson J, Verbiest E. A study of some factors influencing military parachute landing injuries. Aviat Space Environ Med. 1985;56:564–7.
14. Ellitsgaard N. Parachuting injuries: a study of 110,000 sports jumps. Br J Sports Med. 1987;21:13–7.
15. Ellitsgaard N, Ellitsgaard V. Injury producing factors in sport parachuting. J Sports Med. 1989;29:405–9.
16. Amamilo SC, Samuel AW, Hesketh KT, Moynihan FJ. A prospective study of parachuting injuries in civilians. J Bone Joint Surg. 1987;69:17–9.
17. Steinberg PJ. Injuries to Dutch sports parachutists. Br J Sports Med. 1988;22:25–30.
18. Baldwin CC. Parachuting injuries and type of parachute in a reserve rescue unit. Aviat Space Environ Med. 1988;59:780–2.
19. Lowdon I, Wetherhill M. Parachuting injuries during training descents. Injury Br J Accident Surg. 1989;20:256–8.
20. Farrow GB. Military static line parachute injuries. Aust N Z J Surg. 1992;62:209–14.
21. Bagian JP. Comparison of parachute landing injury incidence between standard and low porosity parachutes. Aviat Space Environ Med. 1992;63:802–4.
22. Kragh JF, Jones BH, Amaroso PJ, Heekin RD. Parachuting injuries among army rangers: a prospective survey of elite airborne battalion. Mil Med. 1996;161:416–9.
23. Ekeland A. Injuries in military parachuting (a prospective study of 4499 jumps). Injury. 1997;28:219–22.
24. Craig SC, Morgan J. Parachuting injury surveillance, fort bragg, north Carolina, may 1993 to december 1994. Mil Med. 1997;162:162–4.
25. Dawson M, Asghar M, Pryke S, Slater N. Civilian parachute injuries; 10 years on and no lessons learned. Injury. 1998;29:573–5.
26. Bar-Dayan Y, Bar-Dayan Y, Shemer J. Parachuting injuries-a retrospective study of 43,542 military jumps. Mil Med. 1998;163:1–2.
27. Craig SC, Zugner D, Knapik JJ, Bricknell MC. Parachuting injuries during operation royal dragon, big drop III, fort bragg, north carolina;1996. Mil Med. 1999;164:41–3.
28. Craig SC, Lee T. Attention to detail: injuries at altitude among U.S. army military static line parachutists. Mil Med. 2000;165:268–71.
29. Schumacher JT, Creedon JF, Pope RW. The effectiveness of the parachutist ankle brace in reducing ankle injuries in an airborne ranger battalion. Mil Med. 2000;165:944–8.
30. Barrows T, Mills TJ, Kassing SD. The epidemiology of skydiving injuries: world freefall convention, 2000–2001. J Emerg Med. 2005;28(1):63–8.
31. Westman A, Bjornstig U. Injuries in swedish skydiving. Br J Sports Med. 2007;41(6):356–64.
32. Westman A. Skydiving. In: Mei Dan O, Carmont MR, editors. Adventure and extreme sports injuries. London: Springer; 2013. p. 69–90.
33. Davis JR. Fundamentals of aerospace medicine, vol. 27. 4th ed. Philadelphia: Lippincot Williams & Wilkins; 2008. p. 724.
34. Lo Martire R, Gladh K, Westman A, Lindholm P, Nilsson J, Äng BO. Neck muscle activity in skydivers during parachute opening shock. Scand J Med Sci Sports. 2015. doi:10.1111/sms.12428 [Epub ahead of print].
35. Westman A, Bjornstig U. Fatalities in swedish skydiving. Accid Anal Prev. 2005;37(6):1040–8.
36. Rigou A, Attoh-Mensah J, Geoffroy M, Thélot B. Une estimation des décès traumatiques liés à la pratique sportive en France métropolitaine, en 2010 [An estimation of injury-related deaths linked to sporting practices in metropolitan France, in 2010]. J Traumatologie du Sport. 2013;30:159–65.
37. Mohamed S, Favrod V, Philippe RA, Hauw D. The situated management of safety during risky sport: learning from skydivers' courses of experience. J Sports Sci Med. 2015;14(2):340–6.
38. Technical & Safety Committee; International Parachuting Commission (IPC). IPC SAFETY SURVEY REPORT-*25th Year of IPC Safety Reports*. Fédération Aéronautique Internationale (FAI). 2012. http://www.paracaidismo.org.ar/SYT/Textos/FAI%20Reports/IPCSafetyReport2012.pdf. Accessed Sept 2015.
39. Westman A, Rosén M, Berggren P, Björnstig U. Parachuting from fixed objects: descriptive study of 106 fatal events in BASE jumping 1981–2006. Br J Sports Med. 2008;42:431–6. doi:10.1136/bjsm.2008.046565.
40. Mei Dan O, Carmont MR, Monasterio E. The epidemiology of severe and catastrophic injuries in BASE jumping. Clin J Sport Med. 2012;22(3):262–7.

Foot-Launched Flying Injuries

17

Hang Gliding, Paragliding, Powered Paragliding, and Powered Hang Gliding

Francesco Feletti, Jeff Goin, and Tina Rekand

17.1 Introduction

The term *foot-launched flying* covers different sports, including hang gliding, paragliding, powered paragliding and powered hang gliding. The pilot flies using a paraglider or a hang glider with or without a mechanical propulsion device, launched and landed on foot with no landing undercarriage, wheels, skids or floats attached. The medical literature on injuries in these sports is scarce and fragmented, and these activities are often generically grouped together despite their differences in types of flight, equipment and conditions of practice. Instead, these sports should probably be considered as sharply distinct due to their different injury dynamics and patterns [1].

17.2 Hang Gliding

Hang gliding is the original form of foot-launched flight. The sport has developed since its inception in the 1970s, and today hang gliders are constructed from aluminum alloy, carbon-fiber and high-tech sail fabrics. Modern equipment allows the pilot to cover hundreds of kilometers and to stay aloft for hours at a time. Lifting currents of air allow hang gliders to stay airborne, and pilots usually launch from hills facing into wind running to accelerate to flying speed. In flatlands, hang gliders can be towed aloft behind a microlight aircraft or by a land-based motorized winch (Fig. 17.1). During their flight, pilots are suspended from the glider by a special prone harness, and they control the glider by moving their weight in relation to the control bar. Flying a hang glider is a little more difficult to learn than flying a paraglider and somewhat more demanding, but hang gliders can reach much higher speeds, achieve better gliding performance, and can fly in stronger winds [2]. Although it is possible to perform acrobatics, the vast majority of pilots prefer soaring. Hang gliding competitions are held at national and international levels, and hang gliding is one of the competition categories in the World Air Games organized by the Fédération Aéronautique Internationale (FAI) which maintains the chronology of the FAI World Hang Gliding Championships [3].

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Fig. 17.1 Hang gliding: landing in Florida Ridge, Miami, Florida, USA

17.2.1 Causes of Injuries and Fatalities

Multiple reasons can lead to unsuccessful hang gliding flights resulting in injuries and even fatalities. These include insufficient training and incorrect use of technical equipment as well as misjudgment of weather conditions [12, 13, 15]. In particular, gusty or strong wind conditions have been reported as a determining or contributing cause of incidents in several studies [1, 4, 12, 13, 15, 16]. Given that the aim of the sport is to stay aloft in rising air, launching in the presence of thermal activity is common. Thermals moving at ground level can manifest as gusts, changing the intensity or the direction of the wind both laterally and vertically. Since hang gliders generally land at about 15 mph, a change in wind speed of around 10 mph may be enough to destabilize their flight. Additionally, nearly all hang gliders employ weight shift as their primary control method, where body movement causes changes in pitch (nose up/down) and roll, and strong gusts of wind can easily interfere with this means of control.

Pilot skill plays an important role in safety, and expert pilots have much wider margins of safety in any given weather condition. However, skilled pilots frequently monopolize that margin by taking greater risks such as gliding in bad weather conditions or by using uncertified equipment that can lead to incidents [6]. This is probably why hang gliders with little experience most frequently sustain nonfatal injuries, while pilots with more than 200 flights have a higher rate of fatal incidents [17].

Although equipment failures were uncommonly reported as a cause of incidents and generally did not result in serious events [4, 7–11], inadequate checking of equipment or planning of flights may cause fatal events [18]. The use of alcohol and drugs was also reported as a cause of incidents resulting in injuries or fatalities in some studies [6, 15, 19].

17.2.2 Dynamic of Injuries

Out of 127 hang gliding incidents reported by the United States Hang Gliding and Paragliding Association (USHPA) in the period between 2003 and 2013, 32.2 % ($n = 41$) occurred during takeoff, 36.2 % ($n = 46$) during landing, and 15.7 % ($n = 20$) in flight. Sixteen (12.6 %) towing launch incidents were also reported [11].

17.2.2.1 Takeoff

The most severe injuries are reported immediately after takeoff [4]. The majority of hang gliding takeoff incidents were attributed to insufficient airspeed. This situation can be determined by a launch run which is too brief or too slow causing pushing out or failure to control pitch attitude and angle-of-attack during the launch run [7]. Crosswinds, turbulence or gusty winds can also cause incidents during takeoff. In towed launches, incidents can be due to early releases, releases with insufficient altitude/airspeed or incorrect attachments [7].

17.2.2.2 Flight

Reported in-flight incidents include falls due to turbulence and collisions with buildings, other aircraft or electrical wires [12–14].

17.2.2.3 Landing

The most frequent injuries are reported as a result of landing problems, particularly uncontrolled landings after stalling and landings on hostile ground [5, 6]. Incidents in the landing phase can be caused by uncontrolled contact with the ground while maneuvering to land. This can happen with modern high performance gliders in particular because they tend to accelerate quickly and can rapidly develop high sink rates during un-coordinated turns [11]. Obstacles in the landing zone can contribute to incidents. Precise piloting is paramount on approach. Even minor contact of one wing with an obstruction such as a tree can result in loss of airspeed and rapid yaw, pitch and roll with insufficient altitude for recovery.

17.2.3 Injuries and Fatalities

The extent and severity of reported injuries range from skin lacerations to permanent neurological findings following injuries to the brain or spinal cord. Multiple injuries are common in hang gliding incidents and are reported in most studies [6]. The pilot is suspended from the glider by the harness in a prone position meaning that the head, the upper extremities and the trunk are in a fixed position and prone to injuries. Head injuries are reported as occurring in up to 23 % of cases in the cross-sectional studies and up to 27 % in case series [6]. According to the same reports, the frequency of trunk, spine or spinal cord injuries is between 1 and 34 %, and that of upper extremity injuries is up to 80 % while injuries to the lower extremities is up to 43 % of cases [6]. Some cases of burn injuries related to hang gliding into electrical wires have also been described [6, 14]. The reported fatalities were due to many causes: polytrauma, heart laceration, aorta rupture, pulmonary collapse, skull fractures with brain damage, retroperitoneal hemorrhage and thoracic and cervical spinal cord injury [6, 12, 17, 18]. In their study on fatal aviation incidents, Ast et al. [19] also reported two hang gliding crashes caused by pilot error or loss of aircraft control as a consequence of heart failure. Both cases were attributed to preexisting severe stenosing coronary sclerosis.

17.3 Paragliding

Paragliding is an aerial sport where the pilot flies a modified parachute called a paraglider wing (Fig. 17.2). Paraglider wings derived from skydiving canopies in the 1960s and still have the same fabric cell structure inflated by the wind. They are however not designed to tolerate the terminal velocity opening shock that sport parachutes are required to handle. While parachutes are required to be stronger and employ a staged opening to spread the opening shock (a deceleration from about 120 mph to less than 15 mph in just a few seconds), paraglider wings are designed to stay open and to reopen immediately in case of a wing fold or collapse. Indeed, the wing can fold in various ways, especially when flying in turbulence, usually causing a turn. Although the same phenomenon can affect skydiving canopies, the level of turbulence required is much greater, making it an extremely rare event.

In paragliding, the pilot is suspended from the wing by a network of suspension lines connected to a harness offering support in both the standing and sitting positions. Paragliding requires a slope in order to take off. The wing is inflated by an airstream either from an existing wind or one created by running. Launching is also possible by tow. The pilot uses hand controls called “brakes” connected to the trailing edge of both sides of the wing to adjust speed, steer, and flare during

Fig. 17.2 Red Bull athlete photo shoot with Honza Rejmanek training for the 2011 X-Alps competition in Salt Lake City, Utah. (Photo courtesy of Red Bull Content Pool/Michael Clark)

landing. The wing can also be steered by pilots shifting their weight. An additional foot control called the *speed bar* or *accelerator* attached to the paragliding harness and connected to the leading edge of the wing allows the pilot to increase speed by decreasing the wing's angle of attack. The vast majority of pilots use efficient types of specific wings for soaring. These exploit the rising air from thermals or lifted air over geographic obstructions such as ridges and mountains.

Different wing types are available, depending on their intended use. Special smaller wings (*mini-wings* and *speed-wings*) with more responsive handling and capable of higher speeds have recently been developed (Fig. 17.3) and are used in various disciplines including *speed riding* and *speed flying*. In *speed flying,* a wing about half the size of an average paraglider wing is used to fly in close proximity to a steep slope, generally in strong winds, while *speed riding* (or *ski gliding*) is a winter specialty practiced using skis.

17.3.1 Causes of Injury Events

According to the data collected by the German Paragliding Association, pilot carelessness, lack of experience, changes in wind conditions, and technical failure emerged as the main reasons for incidents from a detailed analysis performed by Schulze et al. [20] on 409 paragliding incidents (Fig. 17.4).

Alpine areas were at higher risk of incidents because of environmental dangers such as tight landing zones, strong valley winds and turbulent thermal conditions, while flights in lowland areas were significantly less dangerous [20].

Beginners and recreational pilots with less than 100 flights were most prone to incidents [20].

17.3.2 Dynamics of Injury Events

The most common dynamic causing approximately one third of incidents is glider collapse or deflation (Fig. 17.5) often occurring following turbulence or gusts of wind. When the pilot is unable to recover from this dynamic, the result is a collision with the ground or with an obstacle [20, 21].

Incidents can occur in every phase of flight, but the most frequent incident types occur on landing. In a retrospective study by Zeller et al. on 376 non-fatal paragliding incidents, 48.7 % occurred during landing, 35.1 % during takeoff, and 16.2 % during flight [21].

17.3.2.1 Takeoff

During takeoff, pilots usually sustain low-energy trauma to the ankle and the upper extremities caused by falls during the fast run downhill

Fig. 17.3 Steve Mayer flying an early speed-wing at Point of the Mountain, Salt Lake City, Utah, USA

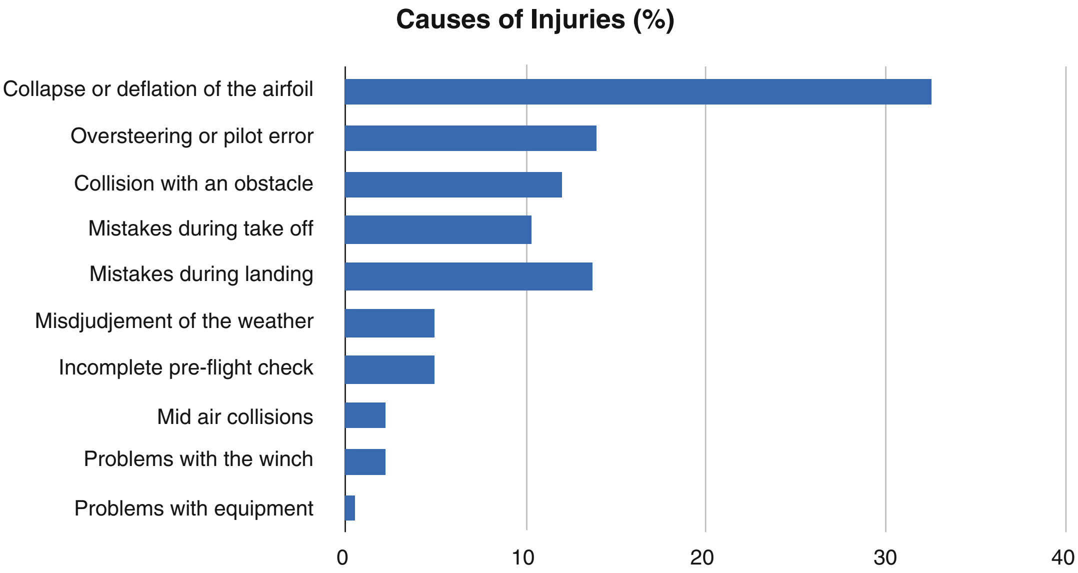

Fig. 17.4 Causes of paragliding incidents [20]

required to inflate the wing. Major spinal injuries reported during takeoff were due to an overestimation of wing lift causing the pilot to sit back too early resulting in slamming the buttocks on the ground [21].

Other less common causes of incidents were due to problems with the winch in towed launches. In these cases, injuries were generally caused by backlash from breakage of the towing cord. An incomplete pre-flight check can also

Fig. 17.5 Asymmetrical collapse. In the series by Schulze et al., an asymmetrical collapse (85.1 %) was a more common cause of incidents than a frontal collapse (15.9 %) [20]

cause incidents. Four fatal events reported by Schulze et al. were caused by failure of pilots to fasten the leg loops causing them to fall out on takeoff. Another incident dynamic was taking off with tangled or knotted lines [20].

17.3.2.2 Flight

During flights, a stall or collapse of the canopy (usually as a consequence of turbulence) can cause crashes from a great height leading to multiple injuries including fractures to the spine, pelvis and lower extremities. One highly dangerous situation involves the tips of the paraglider becoming entangled in its own lines following a full or partial stall resulting in spinning. This situation normally occurs almost exclusively among sport class, high-performance or competitive paragliders (categories 2 and 3 as per the quality categories used by the German Paragliding Association, the ACFPULS – Association des Constructeurs Français de Planeurs Ultra-Légers Souples/French Designing Engineers Association of Microlight Planes and the SHV – Schweiserischer Hängegleiterverband/Swiss Paragliding Association) [20]. Mid-air collisions with other paragliders or hang gliders are possible but rare events (2.2 %; $n = 9$) [20].

17.3.2.3 Landing

Mistakes during landing include landing with a tailwind, incorrect approach (too high or too low), fast curves close to the ground, and sudden, erroneous correction of direction [20]. In 13.9 % ($n = 57$) of the cases reported by Schulze et al. [20], incidents happened as a result of oversteering or pilot error which is most often a consequence of incorrect break-line handling during high-speed descent maneuvers including B-line stall, parachute flight, *big ears* or steep spirals [20]. Major injuries during landing are generally the result of an excessively rapid descent due to turbulence or pilot error [21]. This phase requires pilots to stall their paraglider wing just above the ground and may result in a hard landing if performed too early. During landing, legs bend and absorb part of the impact. Landing with straight legs may cause varying degrees of injury. Mistakes during landing most often occur in hostile environmental conditions such as restricted or difficult landing areas, particularly those with strong winds or strong thermal activity. Collisions with obstacles on land, especially during landing, such as trees (78 %) but also buildings and vehicles represented 12 % of incidents ($n = 49$) [20]. Even more dangerous, although rare (6 %), are crashes into cable cars or into electrical lines which may cause burn injuries [6, 20].

17.3.2.4 Emergency Parachute Deployment

Schulze et al. [20] also reported 39 cases in which emergency parachutes were used. Among these, there were ten cases of serious injuries and three fatalities. One pilot died due to the impossibility of opening the parachute due to having secured the deployment mechanism too tightly, and two pilots died after deploying their emergency parachutes too close to the ground. Emergency parachute deployment was followed by injuries in some instances. In three cases, the emergency parachute was too small. In two cases, the emergency parachute did not open completely or wrapped itself around the glider. In two cases, the emergency parachute was deployed at too low an altitude in order to open quickly enough to function adequately. Finally, in one case, the pilot hit the ground in an unfortunate position due to the extreme oscillation of the emergency parachute. Two pilots were injured by landing on rocky ground.

17.3.3 Injuries

The injuries sustained in paragliding tend to affect different parts of the body in comparison with those sustained in hang gliding. Due to their sitting position, paragliding pilots are more susceptible to lower limb and lower back injuries. Lower limb injuries represent up to 47 % of the total [6, 21, 23] and injuries to the spine and spinal cord are reported in up to 45 % of injured athletes [24]. Multiple injuries are common in paragliding, and a concurrence of lower limb and lower back fractures is a characteristic result [6, 26].

In their analysis of paragliding incidents in remote areas, Fashing et al. [30] found that fractures represented 84 % ($n = 32$) of lower extremity injuries. According to Zeller et al., 80.5 % ($n = 178$) of lower limb injuries were to the lower leg including 120 fractures or ligament injuries to the ankle. Meniscal and ligament injuries of the knee represented 15.3 % ($n = 34$) [23]. The pathogenetic mechanism of ankle injuries involves a combination of compression and rotational forces due to a forced pronosupination movement of the joint [33].

Analysis by Schmitt and Gerner [22] of all sport injuries causing paraplegia or tetraplegia found that paragliding causes more spinal injuries than many other sports. Hasler et.al. as well as many other studies on paragliding injuries [20–22, 24, 28] found a high occurrence of spinal injuries, particularly vertebral body compression fractures (type A, according to the comprehensive classification of thoracic and lumbar injuries by Magerl et al. [27]). Spinal fractures (Fig. 17.6a, b) may occur at any level, but are more often located in the lower thoracic or upper lumbar regions since the pilot is in a seated position, and the energy which causes such injuries is mainly distributed to the thoracolumbar junction [21, 24, 28]. In particular, L1 and Th12 are involved in 25.2 % and 18.5 % of the vertebral fractures respectively (in a series of 119 athletes) according to Zeller et al. [21].

Among the airborne injuries studied by Hasler et al., spinopelvic dissociations were found in the subgroup of paragliders only with a 21 -times greater odds ratio than in the general trauma population [25]. Flexion (type 1 and 2) and extension (type 3) (Fig. 17.7) spino-

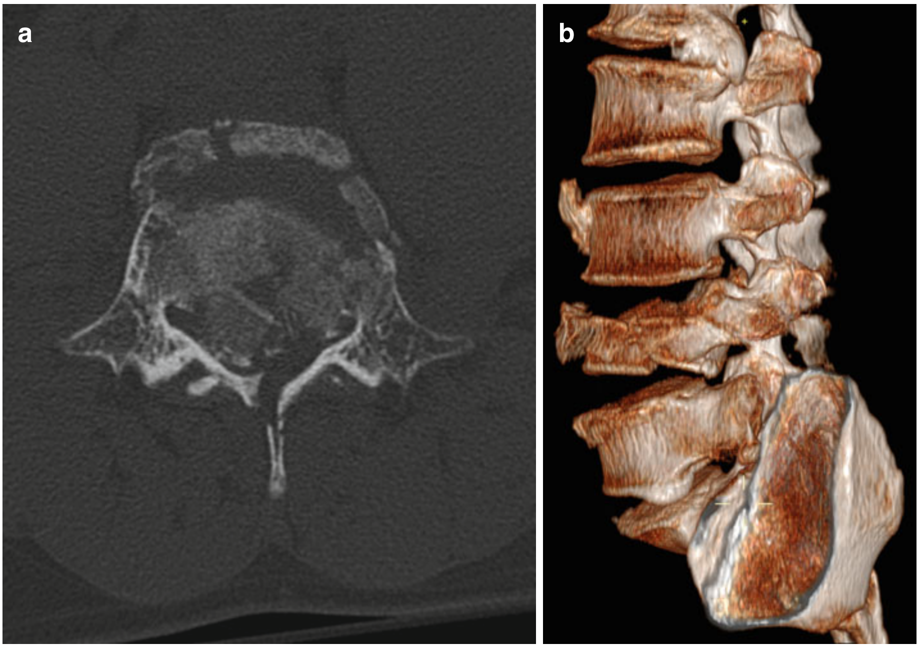

Fig. 17.6 L4 burst fracture in a 47-year-old paraglider resulting from a landing on the buttocks without any kind of back protection following deflation of the wing during approach. (**a**) CT axial scan of L4. (**b**) Volume-rendering 3D reconstruction

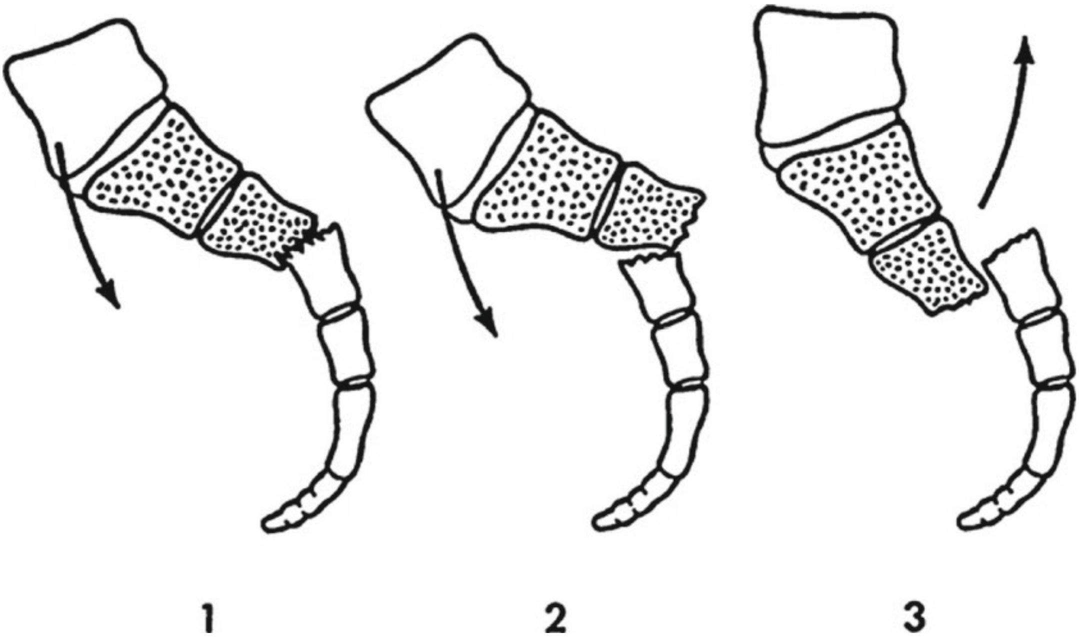

Fig. 17.7 Roy-Camille classification of spinopelvic dissociations (also called suicidal jumper's fracture, or U-shaped sacral fractures) [20, 29]: type 1, flexion fracture; type 2, flexion with displacement of the distal sacral fragment anterior to the proximal tract; type 3, extension fracture with posterior displacement of the distal sacral fragment (Image reproduced with permission from Hasler et al. [25])

pelvic dissociation fractures were equally represented, but the rate of the latter was higher in paragliding than in the general trauma population. Type 1 and 2 spinopelvic dissociations (Fig. 17.7) may be a consequence of the position assumed spontaneously as unintentional means of protection during paragliding landing, whereas type 3 injuries may occur when, during landing, the inertia of the axially and horizontally moved mass of the torso forces the lumbar spine into lordosis, adding horizontal force vectors to the impact.

Head injuries, although less common in paragliders than in hang gliders, have nevertheless been reported in a number of studies [21, 24, 30]. The reported head injuries included concussions, brain contusions and major brain damage as well as minor injuries such as soft tissue trauma, nose fractures and loss of teeth [23, 24]. Although upper extremity injuries are mostly rebound injuries after colliding with the ground, dislocation of the shoulder is also common as a consequence of the particular movement performed when pulling up the sail [23].

17.3.4 Injury Outcome and Protection

Injury outcomes vary from complete recovery to permanent injury of the nervous system to fatality as the worst-case scenario. There are few studies showing long-term outcomes of paragliding injuries, but cases resulting in disability are reported in all series. Paraplegia along with other neurological deficits has been reported in several studies [20, 22, 24, 28]. Persistent neurological impairment is a common consequence of spinopelvic dissociation. Nerve roots below L5 may be strained, compressed by fracture fragments, or completely disrupted, sometimes leading to permanent loss of bowel and/or bladder control [25]. Fatal cases have been reported as a consequence of severe head and cervical spinal cord injuries.

While the number of paragliding participants has increased, the total rate of injuries has decreased over time [31]. This decline may be explained by better training, improvement of equipment, and the protective measures adopted by pilots. In Germany and Austria, for example, following introduction of a new spine protector system, the number of vertebral fractures decreased significantly between 2000 and 2003 [31]. A number of safety measures are now widely adopted by paragliders; the use of shock-absorbing footwear which protects the ankle has become standard while helmets are a legal requirement almost everywhere [20]. Education has focused on pitfalls in flight planning, and most lower extremity injuries could be avoided by responsible flight conduct. Qualified instruction, regular training, and equipment development based on data from well-conducted scientific studies on injuries will help to further improve safety in paragliding. Better understanding of aerodynamics and landing techniques in particular may reduce the risk of paragliding incidents [28].

17.4 Powered Paragliding

Powered paragliding or paramotoring is a sport in which pilots fly using a paraglider wing wearing a motor on their back to take off (Fig. 17.7). The use of a motor frees pilots to fly with no need for thermals or wind and allows take off from flat areas (Fig. 17.8). To avoid a bumpy ride, paramotor pilots typically fly in the mornings and evenings when thermal turbulence is low. As early powered paragliders increased in efficiency, they eventually reached the point where the thrust required was minimal. While early versions may have required 30 horsepower to fly, current models can manage with as little as 10 horsepower.

17.4.1 Causes of Injury Events

A paramotor is flown very differently from a paraglider or a hang glider resulting in injury dynamics and patterns almost entirely distinct from each other. In a cross-sectional study on 384 incident reports gathered by the US Powered Paragliding Association from 1995 to 2012, the primary cause of incidents was attributed to pilot error alone in 53.5 % ($n=205$) of cases, mechanical failure in 17.5 % ($n=67$) of incidents, while weather conditions alone were responsible for incidents in just 5.7 % ($n=22$) of cases [32]. The role of weather conditions, therefore, is lower than in paragliding [21]. Indeed, the thrust of the engine allows the paramotor pilot to take off and fly without the need for strong winds or thermals, hence in safer and more stable weather conditions.

At the same time, however, the versatility of the paramotor wing coupled with its ability to fly anywhere allows pilots to explore higher-risk areas such as those over water. Immersion in water is particularly feared among paramotor pilots because the weight of the engine can rapidly drag pilots under the surface giving them no time to free themselves from the equipment. Actually, 71.4 % of the powered paragliding incidents involving water immersion were fatal [32]. Paramotor flying also allows steep maneuvering low to the ground which produces its own set of incidents. Although free flyers (non-motorized hang-gliders and paragliders) often perform acrobatics, they tend to do so at higher altitudes. Since the engine allows pilots to recover height rapidly, some paramotor pilots perform steep flying close to the ground putting themselves at a higher risk. Steep spirals are particularly dangerous maneuvers in powered paragliding. The position of the pilot and the centrifugal acceleration increased by the thrust of the engine may reduce blood supply to the brain with the potential to cause a momentary state of mental confusion or even blackouts at a time when the maximum level of attention is required [33]. The engine itself can also be a direct cause of incidents. Contact with the propeller caused 11.22 % ($n=43$) of incidents and was responsible for the majority of injuries to the upper limbs [32].

17.4.2 Dynamics of Injury Events

17.4.2.1 Takeoff

According to the previously mentioned series [32], takeoff was the most dangerous phase of flight in powered paragliding; 32.8 % ($n=126$) of incidents occurred during this phase, a percentage which increases to 42.9 % if extended to include incidents during run-up ($n=17$) and

Fig. 17.8 Tim Kaiser flying his paramotor in central Florida; cruising (**a**) and landing (**b**)

inflation ($n=22$) which are considered integral parts of paramotor takeoff. On the other hand, both in paragliding and in hang gliding, landing is the most dangerous phase of flight. During powered paragliding takeoff, the motor exerts its thrust on the crew (suspended from the wing by means of long cables) and on the wing itself despite not being, however, directly connected to it. This makes takeoff a critical phase in powered paragliding since it requires balance between engine thrust, crew weight and lift of the wing. Another contributing factor is the modality of the takeoff itself. While paragliding requires a descent to take off resulting in a rapid increase in distance from the ground, a paramotor can take off from level ground thanks to the power of the engine allowing the powered paraglider pilot to move slowly away from the ground. As a consequence, the falling distance remains low for much longer during takeoff, limiting the possibility of adopting emergency maneuvers including use of an emergency parachute.

17.4.2.2 Flight

In the cross-sectional study recently published by the authors [32], 27.9 % ($n = 107$) of incidents occurred during cruising; in particular, falls during flight represented 9.7 % of incidents, and collision with other aircrafts/ultralights was reported as a cause of incidents in 3.6 % of cases.

17.4.2.3 Landing

In the aforementioned series [32], only 14 % ($n = 55$) of incidents occurred during and after landing, and hard landings represented 10.4 % of powered paragliding incidents.

17.4.3 Injuries

Powered paragliding injuries were found to have the following anatomical distribution: 44.5 % to the upper limbs ($n = 114$), 32 % to the lower limbs ($n = 82$), 9.7 % to the back ($n = 25$), 3.1 % ($n = 8$) to the pelvis, 7 % ($n = 18$) to the head, and 2.7 % ($n = 7$) to the chest [32]. The different distribution of injuries between the upper and lower limbs and the lesser involvement of the spine in powered paragliding than in paragliding is due in part to the different dynamics of the incidents discussed above, and in part to accidental contact with engine parts resulting in injuries specific to this sport [32]. Contact with the propeller caused the majority of injuries to the upper limbs, particularly deep wounds, fractures and fractures with amputation involving hands, wrists (Figs. 17.9 and 17.10), forearms, arms, and shoulders, while contact with hot engine parts was reported as the cause of burns to the face, neck, back, shoulder, arm, elbow, forearm, calf, thigh and ankle. Two cases of generalized burns were the result of a fire caused by combustion of the engine fuel.

In powered paragliding as opposed to paragliding, the thrust of the engine and the weight of the equipment must also be considered as elements with the potential to aggravate the dynamics of injury in case of an incident. High-speed impact injuries including a case of diffuse axonal injury have been documented in this sport, and drowning is a common consequence of water immersion due to the engine weight [32, 35]. Although powered paragliding is widely believed to be safer than paragliding (and fatalities considered to be rarer than in paragliding), 6 % ($n = 23$) of incidents in powered paragliding were found to be fatal [32], a figure that is comparable with 6.1 % of fatalities reported in paragliding by Schulze et al. [20].

Of the 23 fatal incidents reported in powered paragliding [32], death was caused by severe head trauma in four cases. Two were fatal due to cerebral spine fractures with spinal cord damage, and another five fatalities were the result of drowning following an involuntary landing in water. In one of these last cases, the autopsy revealed the cause of drowning to be head injury with hemorrhage and loss of consciousness. In all the remaining cases, death was the result of high-energy polytrauma.

17.4.4 Safety Equipment

Mounting a *safety ring* on the engine cage may help prevent injuries due to contact with the spinning prop. It consists of a ring of the same radius as the prop mounted just forward of the radial arms [32], and it is designed to make it difficult for the upper limbs to reach the prop. Made from aluminum, the *safety ring* is an inexpensive addition and adds very little to the equipment in terms of weight. An auto-inflating flotation device is an essential piece of safety equipment for pilots wishing to fly a paramotor over or near water. It is mounted on the paramotor frame and activated by a CO2 cartridge which fires on submersion with no pilot input required.

Although head injuries accounted for just 7 % of all injuries in our study, these can be potentially severe. Diffuse axonal injury may be a consequence of powered paragliding incidents even in cases where the pilot was wearing a helmet due to the fact that the effectiveness of the helmet may be limited by the direction and intensity of the deceleration [35]. Diffuse axonal injury is caused by angular accelerations and occurs as a consequence

Figs. 17.9 and 17.10 Serious lesions to the upper arms caused by contact with the engine prop; these injuries are specific to powered paragliding. Photo courtesy of US Powered Paragliding Association (USPPA) [34]

of lateral rather than frontal decelerations, while helmets decrease linear head accelerations with limited effects in side impact conditions. Similar results have emerged from helmet studies on skateboarding [36], and the possibility of a fall involving higher angular head accelerations should be considered in studies of protective headgear systems in powered paragliding as well as in other extreme sports. In the traditional motor sports field, new shell and liner materials with properties optimized to minimize head and brain loads in radial, tangential and oblique impacts are constantly being developed [37]. In all probability, the same technology should be applied to the production of helmets for powered paragliding in the future, but further research into the biomechanics of traumatic brain injuries in motorized, foot-launched flying sports is needed.

17.5 Powered Hang Gliding

Powered harnesses are powered units which can be attached to any hang glider with a rigid frame, usually a delta wing. They require significant skill due to the higher running speed involved in foot launching and landing and the resulting difficulty. They are not commonly used and are flown almost exclusively by experienced pilots. They are rarely used for training by inexperienced hang glider pilots (Fig. 17.11).

Hang glider trikes represent a distinct subtype of powered hang gliding. They are wheeled crafts that use a heavier, purpose-built hang glider wing. More commonly grouped together with ultralights or microlights, they are not dealt with here. Pilots learn on these just like other powered aircraft, and although there is some overlap, most are not former or current foot-launched hang glider pilots (Fig. 17.12).

17.5.1 Injuries and Fatalities

The BHPA incident reports collected between 2001 and 2012 included 24 events involving powered hang gliders [1], most of which (82.5 %) took place with wind speeds lower than 20 knots (37 km/h) and without thermals. Powered hang gliding is usually practiced in calmer conditions than those required for non-motorized, foot-launched fight sports since the motor renders thermals unnecessary to gain altitude while strong winds increase the effects of mechanical turbulence and are widely considered to be dangerous [1]. The most commonly reported causes

Fig. 17.11 Powered hang glider during takeoff

Fig. 17.12 Hang glider trike (Photo: Jeff Nielson)

of incidents were pilot error (45.8 %), engine malfunction (16.6 %), and hang glider failure (12.5 %), while weather conditions were rarely held liable for incidents (4.2 %).

One half of the incidents caused injuries, and one was fatal. Half of the injured patients sustained multiple injuries; more than one third (35.7 %) of injuries involved the head/facial region including two facial contusions, one concussion and one case of brain injury, while the rest of the injuries were equally distributed between the trunk and the upper and lower limbs. Generalized injuries included two cases of bruising and two cases of electric burns, one fatal and the other affecting 15 % of the body surface. Although the limited sample size does not permit us to draw any general conclusions with regard to injuries, it seems that the head is often affected by injuries in powered hang gliding, a result in keeping with that previously reported in hang gliding [1].

Conclusions

The term *foot-launched flying* groups together a number of sports which are actually characterized by different injury rates, injury dynamics, and injury patterns due to the different kinds of flight, equipment and conditions of practice in each. In powered paragliding, for example, most incidents occur during takeoff, while in paragliding and hang gliding, most of these occur during landing.

In hang gliding, the pilot is suspended from the glider by the harness in a prone position, while in paragliding the harness offers support in both standing and sitting positions. As a result, injuries to the head, the upper limbs, and cervical spine are more common in hang gliding, while injuries to the ankle and thoracolumbar spine are more common in paragliding. Serious hand lesions caused by contact with the engine prop are specific to powered paragliding. Weather conditions seem to be implicated less often in motorized sports incidents, while the engine and its thrust can be the primary cause or may aggravate the outcome. This may be a reasonable explanation for our recent findings of fatal outcomes of 4.1 % and 4.9 % in powered hang gliding and powered paragliding respectively. These were significantly higher than the value of 2.5 % we found in both hang gliding and paragliding [1].

For these reasons, we believe that foot-launched flying sports should be considered separately in future studies. A final consideration is that reported injuries in foot-launched flying sports are always sudden-onset injuries. There are no reports of overuse injuries in these sports [6], and this may be due to the greater focus on reporting more life-threatening or debilitating injuries. It is our belief, therefore, that more attention should be paid to studying overuse injuries in these sports.

References

1. Feletti F, Aliverti A, Henjum M, Tarabini M, Brymer E. Incidents and injuries in foot launched flying extreme sports: a snap shot from the UK. [Under consideration for publication].
2. British Hang Gliding and Paragliding Association. http://www.bhpa.co.uk/sport/hang_glider. Accessed Mar 2015.
3. Fédération Aéronautique Internationale. http://www.fai.org/record-hang-gliding-and-paragliding. Accessed Mar 2015.
4. Yuill GM. Icarus's syndrome: new hazards of flight. BMJ. 1977;1:823–5.
5. Reymond MA, De Gottrau P, Fournier PE, Arnold T, Jacomet H, Rigo M. Traumatology in hang-gliding accidents. Studies based on 100 cases. Chirurg. 1988; 59(11):777–81.
6. Rekand T. The epidemiology of injury in hang-gliding and paragliding. Med Sport Sci. 2012;58:44–56.
7. Johns T. Hang gliding accident summary. 2003. http://www.ushpa.aero/safety.asp. Accessed Mar 2015.
8. Gregor J, Vant-Hull B. Summary of Non-fatal hang gliding accidents. 2004. http://www.ushpa.aero/safety/HG2004AccidentSummary.pdf. Accessed Mar 2015.
9. Gregor J. Hang gliding accident summaries. 2005. http://www.ushpa.aero/safety/HG2005AccidentSummary.pdf. Accessed Mar 2015.
10. Gregor J, Dickert B. Accident summaries. 2007. http://www.ushpa.aero/safety/HG2007AccidentSummary.pdf Accessed Mar 2015.
11. The United States Hang Gliding and Paragliding Association. Hang gliding and paragliding fatalities January 2013 through July 2013. http://www.ushpa.aero/safety/fatality_report_2013.pdf. Accessed Mar 2015.
12. Bell M. Hang- gliding injuries. Injury. 1978;8: 148–50.
13. Davidson CS. Hang- gliding injuries. N C Med J. 1983;44:439–40.
14. Mang WR, Karpt PM. Injuries from hang- gliding (Article in German). Fortschr Med. 1977;95(1575):1578–9.
15. Krissoff WB, Eisenman B. Injuries associated with hang- gliding. JAMA. 1975;233:158–60.
16. Krissoff WB. Follow- up on hang- gliding injuries in Colorado. Am J Sports Med. 1976;4:222–9.
17. Tongue JR. Hang- gliding injuries in California. J Trauma. 1977;17:898–902.
18. Van Doorn RR, De Voogt AJ. Glider incidents: an analysis of 143 cases: 2001–2005. Aviat Space Environ Med. 2007;78(1):26–8.
19. Ast FW, Kernbach-Wighton G, Kampmann H, Koops E, Püschel K, Tröger HD, et al. Fatal aviation accidents in Lower Saxony from 1979 to 1996. Forensic Sci Int. 2001;119(1):68–71.
20. Schulze W, Richter J, Schulze B, Esenwein SA, Büttner-Janz K. Injury prophylaxis in paragliding. Br J Sports Med. 2002;36:365–9.
21. Zeller T, Billing A, Lob G. Injuries in paragliding. Int Orthop. 1992;16:255–9.
22. Schmitt H, Gerner HJ. Paralysis from sport and diving accidents. Clin J Sport Med. 2001;11(1):17–22.
23. Christey GR. Serious parasport injuries in Auckland. New Zealand Emerg Med Australas. 2005;17(2):163–6.
24. Krüger-Franke M, Siebert CH, Pförringer W. Paragliding injuries. Br J Sports Med. 1991;25:98–101.
25. Hasler R, Hüttner HE, Keel MJB, Durrer B, Zimmermann H, Exadaktylos AS, et al. Spinal and pelvis injuries in airborne sports: a retrospective analysis from a major Swiss Trauma Centre. Injury. 2012; 43:440–5.
26. Gauler R, Moulin P, Koch H, Wick L, Sauter B, Michel D, et al. Paragliding accidents with spinal cord injury: 10 years' experience at a single institution. Spine. 1996;31:1125–30.
27. Magerl F, Aebi M, Gertzbein SD, Harms J, Nazarian S. A comprehensive classification of thoracic and lumbar injuries. Eur Spine J. 1994;3(4):184–201.
28. Rekand T, Schaanning EE, Varga V, Schattel U, Gronning M. Spinal cord injuries among paragliders in Norway. Spinal Cord. 2008;46(6):412–6. doi:10.1038/sj.sc.3102158. Epub 2008 Jan 8.
29. Roy-Camille R, Saillant G, Gagna G, Mazel C. Transverse fracture of the upper sacrum Suicidal jumper's fracture. Spine (Phila Pa 1976). 1985;10(9): 838–45.
30. Fasching G, Schippinger G, Pretscher R. Paragliding accidents in remote areas. Wilderness Environ Med. 1997;8:129–33.
31. Bohnsack M, Schröter E. Injury patterns and typical stress situations in paragliding. [Article in German]. Orthopade. 2005;34(5):411–8.
32. Feletti F, Goin J. Accidents and injuries related to powered paragliding: a cross-sectional study. BMJ Open. 2014;4:e005508. doi:10.1136/bmjopen-2014-005508.
33. Laver L, Mei Dan O. Paragliding injuries. In: Mei Dan O, Carmont MR, editor. Adventure and extreme sports injuries. London: Springer – Verlag; 2013. Schneider S, Abein V, Askew CD, et al. Changes in cerebral oxygenation during parabolic flight. Eur J Appl Physiol 2013;113:1617–23.

34. USPPA – United States Powered Paragliding Association. http://www.usppamembers.org. Accessed Mar 2015.
35. Feletti F. Multiple injuries in paramotoring: a case report to assess this sport's risks. Am J Sports Sci. 2013;1(1):7–11. doi:10.11648/j.ajss.20130101.12.
36. Kumar S, Herbst B, Strickland D. Experimental biomechanical study of head injuries in lateral falls with skateboard helmet. Biomed Sci Instrum. 2012;48:239–45.
37. McIntosh AS, Andersen TE, Bahr R, Greenwald G, Kleiven S, Turner M, et al. Sports helmets now and in the future. Br J Sports Med. 2011;45:1258–65.

Paragliding Medicine

18

Lorin M. Benneker and Peter M. Haefliger

18.1 Introduction

Paragliding was developed in the early 1980s by mountaineers who were searching for a fast and easy way to descend from mountain peaks and by flight enthusiasts seeking to become airborne without the use of a motor. In the 1950s, Domina Jalbert (1904–1991) invented a wing similar to modern paragliders, with a design known as *ram air*: sectioned cells in an aerofoil shape, an open leading edge and a closed trailing edge. Over the past 30 years, paragliding has seen significant advancements in design and technique. The first gliders were adapted parachutes with a multiple chamber profile, a glide ratio of 1:2.5, and an aspect ratio (wing depth/square of span) of around 3. In comparison, today's high-performance gliders have a glide ratio of more than 1:12 and an aspect ratio of nearly 8 (Figs. 18.1 and 18.2).

18.2 Incidents and Injuries

Epidemiological data on injuries in paragliding are mainly from retrospective case series or cross-sectional studies: calculation of injury rates is difficult, since the precise number of paragliders is usually unknown. No studies on degenerative changes as a result of overuse are reported in paragliding, and all the available series are related to traumatic events [1–5]. A survey from Germany analyzed over 400 incidents over a period of 3 years and calculated yearly incident rates of licensed pilots of 0.58–1.01 %, severe injury rates of 0.32–0.5 %, and mortality rates of 0.03–0.06 %, all decreasing over time [6]. In Switzerland, 129 incidents were reported over 3 years, 9 were fatal incidents and 60 of those classified caused major injuries [7].

Incidents in paragliding most commonly occur as a consequence of deflation of the glider (32.5 %), oversteering (13.9 %), landing errors (13.7 %), collision with obstacles (12.0 %), and takeoff errors (10.3 %) [6]. Any disturbance of the chute's profile results in a loss of height: if there is an adequate distance to the ground, such disturbances can be corrected by the pilot, and a stable forward motion can be obtained. A large unilateral collapse of the airframe results in a spin and helical flight path, a spiral dive where the vertical speed can easily reach 20 m/s (72 km/h). Due to the large pendulum of the pilot suspended 8 m below the wing, the centrifugal forces may accelerate the pilot to speeds of over

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Fig. 18.1 Intermediate paraglider from 1987

Fig. 18.2 High-performance paraglider from 2012

100 km/h. By vector addition, this results in velocities of over 120 km/h for the pilot relative to the land surface. An aerodynamic stall over the whole wingspread (e.g., abrupt braking maneuver) results in a nearly vertical plunge downward, with speeds of around 10 m/s. A unilateral aerodynamic stall leads to uncontrolled rotation around the vertical axis and downward velocities of around 6 m/s.

18.3 Acute Traumatic Injuries

Due to the sitting or semi-recumbent position in the harness (Figs. 18.3 and 18.4), the crashing pilot first impacts with his feet or buttocks.

Accordingly, most injuries are observed in the lower extremities and the trunk (pelvis and spine): fractures, dislocations, distortions, and

Fig. 18.3 Recreational harness

Fig. 18.4 Competition harness with streamlined leg cover

strains of the lower extremities account for 27–46 % of these injuries, with injuries to the spine and trunk representing 31–60 % of all reported paragliding injuries [2–5, 8, 9].

In the spine, the most common injuries (50–91 %) are severe compression-type fractures, requiring surgical treatment in two-thirds of patients, while one-third of patients present neurological impairment [2, 5, 7]. In a Swiss study, in 12 out of 37 patients with spinal cord injury, the level of the neurological damage and that of the vertebral fracture differed by two segments: the authors assume that the particular injury mechanism responsible for these injuries, involving mainly axial forces compressing or stretching multiple segments at once, explains this difference to the non-paraglider paraplegic patients [2]. There is a typical peak at the thoracolumbar junction, with L1 as the most affected vertebra (30–35 %), as compared to the fracture distribution in general trauma where another similar peak at the lower cervical spine and a third smaller peak at the mid-thoracic spine are described [2, 5, 8].

In paragliding incidents, injuries to the cervical spine (6–8 %) and head (5–16 %) are relatively rare, but the total frequency of spinal and pelvic injuries is far higher as compared to general and sports trauma and highlights the danger of the massive impact forces at deceleration [2–5, 9]. The spinopelvic junction has been identified as being at special risk in paragliding incidents: in a retrospective series, 8 of 144 severely injured paragliders sustained a spinopelvic dissociation, an injury also known as a “suicidal jumper’s fracture” [5] (Fig. 18.5). Compared to the normal trauma population, the injured paraglider has a 19-fold increased risk of sustaining such an otherwise rare fracture. One possible explanation may be the additional horizontal force vectors that occur during the paraglider’s landing, as the inertia of the axial and horizontal moved mass of the torso forces the lumbar spine into lordosis, resulting in flexion-type jumper’s fractures [5, 10].

Non-skeletal injuries are less frequent: severe thoracic, visceral, and vascular trauma are reported, often concomitant to injuries of the spine [9, 11]. Three cases of traumatic rupture of the descending aorta, associated with multiple injuries following a paragliding blunt trauma, have been attributed to the chest being crushed and the sudden brusque deceleration [12]. Cases of myocardial contusion, hematothorax, pneumothorax, and gut and urinary bladder rupture, as well as liver contusion with bleeding, have also been reported [13].

18.3.1 Medical Considerations with Regard to the Dynamic of Injuries

One-third of the incidents occur during the launch phase. Launching with a paraglider requires a fast run downhill from a slope until the sail inflates and provides sufficient lift. Most of the injuries during takeoff involve the ankle, as a consequence of a fall while the pilot is running on the ground. Launch injuries are usually minor. However, major spinal injuries can occur if the pilot overestimates the lifting airstream and sits back too early, landing on his buttocks [3].

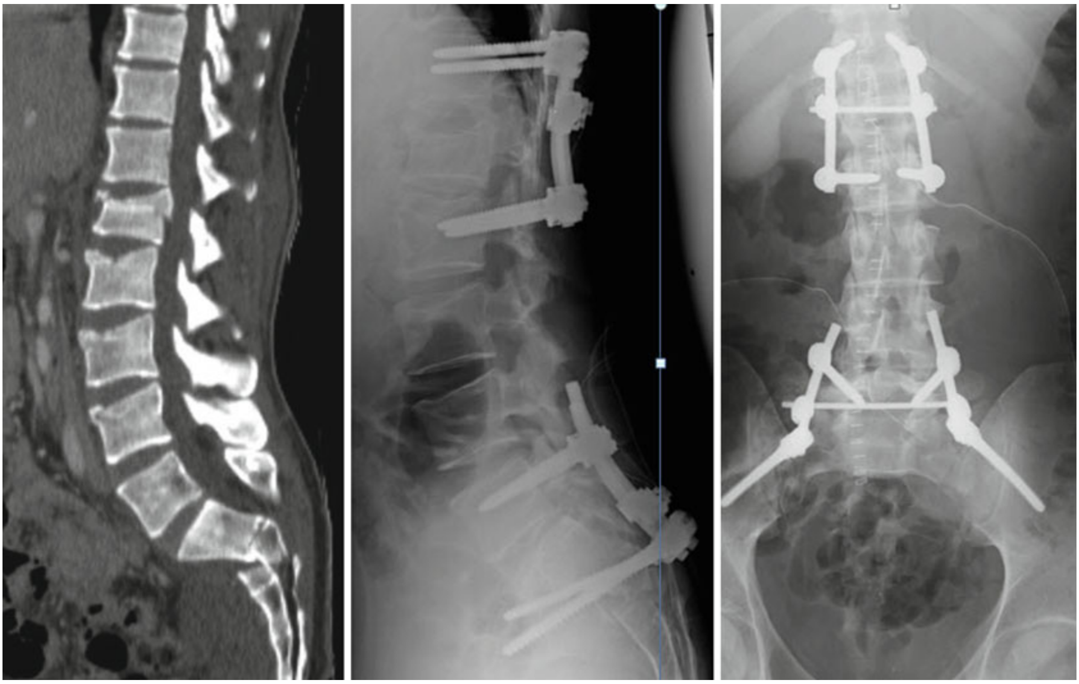

Fig. 18.5 Typical fracture pattern of a 30-year-old paraglider with lumbar compression-type fractures, superior burst-split fracture of L1, flexion type 2 spinopelvic dissociation with impaired S2 and S3 root function

Although in-flight incidents as a consequence of a sail collapse or turbulence are rare (16 %), crashes from a great height can lead to multiple injuries involving fractures of the talus, pelvis, and spine [3]. In these cases, plain radiographs or computed tomography (CT), particularly of the lower spine and pelvis, is essential in order to exclude fractures. Neurological observation is necessary in the short term. In the case of such incidents, ultrasound imaging should also be performed to exclude closed abdominal injuries [3].

The most dangerous phase of the paragliding flight is landing [1, 3, 14, 15]. During landing, the legs can bend and absorb part of the impact. Injuries of various degrees may happen as a consequence of poor technique, such as landing with the legs straight. Large axial compression forces act on the spine and lower limbs at the time of contact with the ground, which predisposes the paraglider to compression fractures of the spine and calcaneus [4]. Uncontrolled landings can occur if the descent is too rapid, due to misjudgment or turbulence: since these may result in high-energy trauma, major injuries should be excluded in all of these cases. In victims of severe paragliding incidents, contrast-enhanced CT should be included in the routine emergency radiologic evaluation, in order to exclude severe injuries, including traumatic aortic rupture [12].

18.3.2 Treatment and Outcome of Paragliding Acute Traumatic Injuries

Initial treatment should strictly follow the ATLS guidelines; the relatively frequent and possibly life-threatening pelvic fractures and deceleration injuries to abdominal organs and vessels need to be ruled out. The same applies to thoracic trauma cases, which are seen in over 20 % of all cases [2, 4, 5, 9]. Careful assessment and documentation of neurological status is mandatory. Selective bladder or bowel dysfunction may be present in spinopelvic dissociation. Spinal fractures are seen mostly at the thoracolumbar junction, but multiple spinal fractures are also common

(17–26 %) and need to be considered in the examination, as well as non-spinal fractures that concomitantly occur in more than half of the patients with severe spinal trauma [2, 5]. Most of these fractures are unstable and require surgical treatment. Indications and technical preferences vary greatly among regions [4, 5].

Over 60 % of injured paragliders are admitted to a hospital. Length of hospital stay varies from 22 to 26 days on average, and the duration of disablement ranges from 80 to 98 days on average. About 43–70 % of patients resumed paragliding [7, 9].

Even patients with severe neurological impairment from spinal cord injury showed a high potential for neurological recovery. In particular, patients with a bony occlusion of the spinal canal of less than 70 % improved substantially, with 13 out of 14 patients ambulatory after the rehabilitation phase of 3–4 months on average (compared to 13 of 19 patients with occlusion >70 %). As expected, patients with type A (vertebral body compression) lesions, according to Magerl et al. [16], recovered better than those with type C fractures (anterior and posterior element injury with rotation) [2]. Nearly all patients with spinopelvic dissociations will present neurological impairment with the nerve roots below the level L5 being incompletely affected: incomplete recovery and persisting bladder and bowel dysfunction are expected [5].

18.3.3 Crashed Pilot Rescue

Especially in remote areas difficult to access with ground vehicles, evacuation of crashed paragliding pilots is very often possible by helicopter only [9]. The use of a helicopter may be also justified by the need for immediate medical support. When approaching a victim of a paragliding incident near a slope crowded with paragliders, the risk of collision of the helicopter with other gliders may be high. Landing the helicopter at the incident site is often impracticable due to the tight spaces, and rescue operations are sometimes possible only by means of a cable winch or a long rope fixed to the helicopter [17]. Since the downwash of the rotor blades could blow the paraglider upward, resulting in a secondary lethal crash if the stranded athlete is still attached to his wing, a direct approach of a helicopter is advisable only if the pilot has secured the scene by detaching and folding his wing.

When a direct approach is appropriate, a long-line rescue with extension of the rope up to 200 m may reduce the risk of downwash, even if this maneuver remains extremely risky for the rescue team. Unfortunately, rescue situations such as these are unusual: generally the rescue team is lowered to the ground as close as possible to the incident scene and walks or climbs to reach the stranded pilot.

There are cases of crashed pilots stranded on the cables of a cable car [9], and specific evacuation techniques are required in these situations. The emergency physician should perform a careful examination of the pilot, despite the challenging environmental conditions. Knowledge of the injury pattern typically sustained by crashed paraglider pilots is a valuable aid when formulating the primary diagnosis, important when deciding the most appropriate care facility for the victim, based on the specific injuries sustained [9]. It is vital to stabilize the patient before starting transportation: this should include securing the airways, immobilizing the spine, stabilizing fractures with the aid of a vacuum mattress, and beginning infusion and analgesics [9].

18.4 Musculoskeletal Injuries Due to Specific Patterns of Movements

Musculoskeletal, ligament, and tendon injuries related to functional overload and to the specific patterns of movements required in paragliding are rarely reported, probably because more attention has been paid to injuries resulting from high-energy trauma injuries up to now; however they are probably underestimated. Shoulder dislocation, for example, is a common paragliding injury and may be a consequence of the particular movement required when pulling up the sail [18]. Schulze Bertelsbeck et al. [19] also reported the case of a pilot who sustained a bilateral partial rupture of the rectus femoris muscle during a paragliding landing maneuver. Rupture of the rectus femoris muscle is a rather uncommon condition: the rectus femoris is the only biarticular muscle in the quadriceps, making it prone to muscle strain injuries when undergoing eccentric contractions [20–23]. During a paragliding landing, the pilot absorbs energy through his legs [3], and the quadriceps exerts an eccentric contraction to counteract the impact: accordingly, the rectus may be subject to strains and ruptures during landings with a paraglider. Effective strategies to prevent such injuries, therefore, may include an appropriate flight technique (including a proper reduction of the speed during the approach phase), together with a workout focused on the specific types of efforts required.

18.5 Environmental Illnesses

Various non-traumatic, yet potentially life-threatening conditions are reported in literature: they are characteristic of this extreme sport and are associated with exposure to environmental agents. Although the data in question consists of isolated reports, it takes on greater importance in the absence of systematic sets of data. Physicians should be aware of the potential for these health problems and take them into consideration, both when formulating the primary diagnosis, which often needs to be done rapidly, and when considering suitable strategies for the prevention of these conditions.

18.5.1 Impairment in Mental Faculties Related to High Altitude

Paragliding is commonly considered an extreme sport, but its physical demands are relatively moderate when compared to many other outdoor activities. Average physical fitness is sufficient for this sport; however, above-average coordination, proprioception, and ability to concentrate are necessary.

Mental faculties may be impaired at high altitudes, due to the pathophysiological effects of low oxygen concentrations. A variety of transient focal neurological signs presenting at high altitude, not associated with acute mountain sickness or other concurrent illness, are reported in the medical literature: these conditions include hemiplegia [24], unilateral paresthesia, aphasia [25], dysphasia [26], lateral rectus palsy [27], cortical blindness [28], and other visual disturbances such as scotomata [29]. In paragliding, Milheiro et al. reported a case of transient global amnesia affecting a healthy 33-year-old pilot [30]. The athlete manifested symptoms after a 20-min flight at an altitude of approximately 2000 m: he completed a flawless descent and landing and was completely back to normal in about 5 h, retaining a memory gap for this period. High-altitude global amnesia was first reported by Litch [31] in a series of four patients, all of whom developed symptoms upon rapid ascent to very high or extreme altitude (above 3500 m) and resolving during or soon after descent. The case of a man who experienced transient global amnesia while skiing at 2000 m has also been reported [32]. In this condition, characterized by an abrupt onset of severe anterograde and variable retrograde, memory impairment could result from cerebrovascular spasm, local hypoxia without loss of perfusion, or both, resulting in inadequate oxygenation to the memory center of the brain. At high altitudes, the increase of cerebral blood flow as a consequence of hypoxemia is usually mitigated by the cerebrovasoconstriction from hypocapnia following the increase in ventilation [33]. A particularly strong hypoxic ventilatory response may result in greater hypocapnia, cerebral vasoconstriction, and decrease in brain oxygenation [34]. In addition, individual vasomotor hyperreactivity to the vasoconstrictive effect of hypocapnia may contribute to the development of this condition. Finally, some precipitants including physical exercise are well established. This is a self-limiting condition which does not leave cognitive sequelae and usually does not recur. For patients affected by neurological conditions presenting at high altitude, immediate descent and oxygen supplementation is recommended [35, 36]. Sudden episodes of high-altitude global amnesia while paragliding may cause hazardous situations.

High-altitude paragliding expeditions are becoming more and more common: Mont Blanc (4810 m), Parinacota (6300 m), Aconcagua (6962 m), Manaslu (8156 m), and Mount Everest (8848 m) have all witnessed successful launch attempts in recent years [37]. High-altitude paragliding expeditions expose paragliders to hazards due to adverse environmental conditions, combined with the pathophysiological effects of high altitude. In such situations, preflight fitness assessment tests are recommended [37]. In 2013, the Wings of Kilimanjaro expedition aimed to launch 95 paragliders from Stella point on the summit of Mount Kilimanjaro (5790 m). On this occasion, Wilkes M et al. developed a score to assess the pathophysiological effects of high-altitude preflight, within the context of standard preflight checks: this score (Kilimanjaro score) aimed to assess cognition, memory, and visual-spatial skills [37]. The Kilimanjaro score is structured to be completed rapidly: it involves assigning a score (ranging from 0 to 3) to each of seven points, including a subjective assessment of fitness, four questions assessing cognition and memory, and two assessing visual-spatial skills. Pilot ability to correctly attach their harness and conduct a line check was specifically evaluated, being activities requiring a logical approach, as well as manual dexterity and coordination. The Kilimanjaro score was designed primarily to recognize the neurological symptoms caused by high altitude, but it is important to consider that during a mountain launch, other conditions (such as poor sleep and fatigue, the effects of low temperatures, or infectious diseases) may impair athlete's ability to fly in safety [37].

18.5.2 Frostbite

Frostbite as a result of mountaineering or Arctic expeditions is a well-known problem. A rare case of frostbite injury following a paragliding incident at high altitude has been recently reported by Terra et al. [38]. A cumulonimbus cloud formation rapidly carried the pilot up to approximately 5500 m: he acquired frostbite injuries on about 5 % of his total body surface, including the neck, wrists, hands, and left leg. The frostbite was initially treated by rewarming, with later debridement and local application of silver sulfadiazine and povidone-iodine dressings. All injuries healed within 3 months. Another case of severe frostbite injury involved a very experienced female paraglider in Australia in 2007. While practicing for the Paragliding World Championships, a tornado-like thunderstorm carried her from 2500 ft to an estimated 32,635 ft (9947 m) in about 15 min [39, 40]. She lost consciousness for up to an hour due to lack of oxygen and was exposed to temperatures of −40 °C, being covered in ice and suffering from severe frostbite. Another male athlete died in the same storm, apparently from lack of oxygen and cold: his body was found nearly 50 miles from where he took off.

Frostbite is caused by freezing of the tissues. It is induced by extreme cold, and exposure of just a few seconds may suffice, especially at high altitudes and in the presence of strong winds or on contact with cold metal. The affected part becomes deceptively pain-free, waxy, and white and remains so until thawing occurs. Muscles may be paralyzed, and nerves, arteries, and even bones may be damaged. On rewarming, the extent of the tissue damage becomes apparent. In mild cases, there is erythema and discomfort, with return to normality in a few hours. In more severe cases, tissue destruction and blistering ensue, and this may be superficial, full thickness, or involve deep tissues, as with the classification of burns. Frank gangrene may occur.

It is now recommended that rewarming should be rapid: this can be achieved with a water bath at 40–42 °C. Continuing this treatment beyond 20 min is not useful. Exposure to greater heat must be avoided. Early infusion of low-molecular-weight dextran has also given useful results. Rest and avoidance of further trauma has good influence on the subsequent course of healing. Surgical consultation should always be sought when there is the formation of multiple bullae, gangrene, loss of tissue, or evidence of infection.

18.5.3 Hymenoptera Venom-Induced Anaphylaxis

Feltracco et al. reported a case of fatal hymenoptera venom-induced anaphylaxis during paragliding [41]. A 45-year-old paraglider pilot was seen spinning rapidly toward the ground without any visible attempt to recover control of the wing, apparently unable to steer properly, adjust speed, or safely reduce altitude. The episode was witnessed by another pilot flying his paraglider a short distance away: the victim was found dead by the rescue team, with significant swelling to his face and neck. A red and black spot was seen on the swollen tongue, and a dead bee was found in his mouth. The autopsy concluded that an anaphylactic shock caused the death in midair and that the traumatic injuries to the vital organs were not so severe to admit a death by falling. The victim had suffered an anaphylactic reaction following a bee/wasp sting 10 years previously: the hypersensivity reaction, mediated by vasoactive amines released by basophils and mast cells sensitized by immunoglobulin E, involves the gastrointestinal system, respiratory tract, cardiovascular system, skin, mucosa, and other body systems. In the case reported, it is likely that hypotensive shock, laryngeal edema, and bronchospasm led to asphyxia, brain hypoxia, loss of consciousness, and complete lack of aircraft control. In the summer season especially, contact with insects, including wasps and bees, may occur during paragliding. Since unexpected health problems occurring in midair may impair the pilot's ability to correctly maneuver the paraglider and land safely, patients suffering from hypersensivity to insect venom should consider avoiding flying when contact with these insects may occur. However, this avoidance behavior can be difficult and very limiting. The possibility of carrying a disposable auto-injector on flights, charged with a single dose of solution (0.30 ml, containing 0.33 mg of adrenaline) to be self-injected intramuscularly in case of need, should also be considered.

18.6 Prevention

Incidents related to defective equipment are rare. Most incidents in paragliding are the result of pilot error (oversteering, incorrect break line handling, failure to correct airfoil collapse) or misjudgments when starting, landing, approaching obstacles, or misreading weather conditions [6]. The main goal of injury prevention should therefore be pilot education, since many incidents could be prevented through better preparation and judgment. Good knowledge of the terrain and better landing techniques can reduce the risk of axial compression loading injuries [4]. In most European countries (except France), prospective pilots have to undergo several months of training, with a final practical and theoretical examination. The training focuses on technical and aerodynamic aspects of the paraglider, meteorology, and the idiosyncrasies of flying a soft airfoil at limited speeds (approx. 25–55 km/h).

Protective gear such as a helmet, solid ankle-supportive shoes, and spine protectors should be used during every flight. These days, various shock absorption systems for the back and buttocks area are routinely incorporated into most modern harnesses. They usually consist of foam material-filled protectors or airbag systems that are filled via ram pressure and a large check valve. The best results are seen in protectors that combine both systems. The use of sturdy shoes which enclose the whole ankle joint may reduce the risk of ankle trauma [4]. Immediately before takeoff, a complete preflight check should be carried out. In the case of bad weather conditions, a flight should be canceled or promptly ended [6]. High winds in particular may increase the effect of mechanical turbulence, and a wind speed safety limit of 24 km/h has been proposed. This limit is quite arbitrary, however, and it may change according to different associated variables; in any case, takeoffs should be avoided when there is a tailwind present [13]. Flying in heavy rain or snow can also be dangerous, because the fabric of the wing may adsorb water, gain weight, and lose efficacy as it becomes less stable and controllable. It is very important that the type of paraglider used is suitable for the pilot's level of experience. Some pilots tend to use large canopies to increase the duration of the flight, but this may affect safety in certain conditions. High-performance wings are very sensitive and should be reserved for pilots with a high level of training and experience.

Despite being considered an extreme sport, paragliding is accessible for nearly everybody of average fitness and good physical health, but an adequate physical training program should be combined with an appropriate flight technique, to avoid muscle skeletal injuries due to the specific patterns of movement required in this sport. It is also important, before beginning to practice paragliding and periodically thereafter, that athletes undergo a general health assessment, performed by a doctor who is familiar with all the possible problems related to the sport. Score systems to assess the pathophysiological effects of high altitude should be included in the context of standard preflight checks, especially during high-altitude paragliding expeditions. Finally, the possibility of rare but potentially life-threatening paragliding-related medical conditions, such as frostbite or hymenoptera venom-induced anaphylaxis, also needs to be known and taken into consideration by doctors involved in the assistance of those who practice paragliding.

Conclusions

Various kinds of health problems may occur during the practice of paragliding: these include acute traumatic injuries, musculoskeletal injuries due to the particular movements required by the sport, and environmental illnesses. An awareness of these medical conditions may help physicians in formulating a primary diagnosis, which often needs to be done rapidly and in difficult circumstances. Knowledge of the dangers of this sport can help in identifying and adopting proper means of prevention, including adequate athletic and technical preparation, and periodic assessment of the athletes' general state of health. For these reasons, further medical research on this sport is advisable, in order to better understand the pitfalls related to paragliding and possible solutions.

References

1. Rekand T. The epidemiology of injury in hang-gliding and paragliding. Med Sport Sci. 2012;58:44–56.
2. Gauler R, Moulin P, Koch HG, Wick L, Sauter B, Michel D, Knecht H. Paragliding accidents with spinal cord injury: 10 years' experience at a single institution. Spine (Phila Pa 1976). 2006;31(10):1125–30.
3. Zeller T, Billing A, Lob G. Injuries in paragliding. Int Orthop. 1992;16(3):255–9.
4. Kruger-Franke M, Siebert CH, Pfaerringer W. Paragliding injuries. Br J Sports Med. 1991;25(2):98–101.
5. Hasler RM, Hüttner HE, Keel MJ, Durrer B, Zimmermann H, Exadaktylos AK, Benneker LM. Spinal and pelvic injuries in airborne sports: a retrospective analysis from a major Swiss trauma centre. Injury. 2012;43(4):440–5.
6. Schulze W, Richter J, Schulze B, Esenwein SA, Büttner-Janz K. Injury prophylaxis in paragliding. Br J Sports Med. 2002;36:365–9.
7. Rutti C. Unfallmeldung und erste Auswertung. Swiss Glider. 2004;1:36–7.
8. Rekand T, Schaanning EE, Varga V, Schattel U, Gronning M. Spinal cord injuries among paragliders in Norway. Spinal Cordm. 2008;46(6):412–6.
9. Fasching G, Schippinger G, Pretscher R. Paragliding accidents in remote areas. Wilderness Environ Med. 1997;8(3):129–33.
10. Roy-Camille R, Saillant G, Gagna G, Mazel C. Transverse fracture of the upper sacrum. Suicidal jumper's fracture. Spine (Phila Pa 1976). 1985;10(9): 838–45.
11. Krauss U, Mischkowsky T. The severely injured paraglider: analysis of 122 cases. Unfallchirurg. 1993;96:299–304.
12. Navarrete Navarro P, Macias I, Lopez Mutuberria MT, et al. Traumatic rupture of aorta should be ruled out in severe injuries from paragliding: report of three cases. J Trauma. 2002;52(3):567–70.
13. Laver L, Mei Dan O. Paragliding. In: Mei Dan O, Carmont MR, editors. Adventure and extreme sports injuries. London: Springer; 2013. p. 247–72.
14. Reymond MA, De Gottrau P, Fournier PE, Arnold T, Jacomet H, Rigo M. Traumatology in hang-gliding accidents. Studies based on 100 cases. Chirurg. 1988;9(11):777–81.
15. Lang T, Dengg C, Gabl M. Der Unfall mit dem 'gleitschirm'. Sportverletz Sportschaden. 1988;2: 115–9.

16. Magerl F, Aebi M, Gertzbein SD, et al. A comprehensive classification of thoracic and lumbar injuries. Eur Spine J. 1994;3:184–91.
17. Fasching G, Pretscher R. Helicopter rescue in alpine areas by means of a cable winch. Notfallmedizin. 1992;18:125–8.
18. Christey GR. Serious parasport injuries in Auckland. New Zealand. Emerg Med Australas. 2005;17(2):163–6.
19. Schulze Bertelsbeck D, Veelken D. Paragliding-associated bilateral partial rupture of the rectus femoris muscle. [Article in German]. Unfallchirurg. 2004;107(12):1196–8.
20. Langer PR, Selesnick FH. Proximal rectus femoris avulsion in an elite, olympic-level sprinter. Am J Orthop. 2010;39:543–7.
21. Garrett Jr WE. Muscle strain injuries: clinical and basic aspects. Med Sci Sports Exerc. 1990;22(4):436–43.
22. Garrett Jr WE. Muscle strain injuries. Am J Sports Med. 1996;24(6):2–8.
23. Zarins B, Ciullo JV. Acute muscle and tendon injuries in athletes. Clin Sports Med. 1983;2(1):167–82.
24. Ward M. Mountain medicine. London: Crosby, Lockwood, Staples; 1975.
25. Ward M, Milledge JS, West JB. Central nervous system. In: High altitude medicine and physiology. 2nd ed. London: Chapman and Hall Medical; 1995. p. 324–43.
26. Jenzer G, Bartsch P. Migraine with aura at high altitude. J Wilderness Med. 1993;4:412–5.
27. Murdoch DR. Lateral rectus palsy at high altitude. J Wilderness Med. 1994;5:179–81.
28. Hackett PH, Hollingshead KF, Roach R, Schoene RB, Mills WJ. Cortical blindness in high altitude climbers and trekkers-a report on six cases [abstract]. In: Sutton JR, Houston CS, Cotes G, editors. Hypoxia and cold. New York: Praeger Press; 1987.
29. Houston C. Transient visual disturbances at high altitude. In: Sutton JR, Houston CS, Cotes G, editors. Hypoxia and cold. New York: Praeger Press; 1987.
30. Milheiro I, Rocha S, Machado A. Falling (or ascending) into oblivion: transient global amnesia with paragliding. J Neuropsychiatry Clin Neurosci. 2011;23:40. doi:10.1176/appi.neuropsych.23.4.e40.
31. Litch JA, Bishop RA. High-altitude global amnesia. Wilderness Environ Med. 2000;11:25–8.
32. Bucuk M, Tomic Z, Tuskan-Mohar L, et al. Recurrent transient global amnesia at high altitude. High Alt Med Biol. 2008;9:239–40.
33. Severinghaus JW, Chiodi H, Heger EI, et al. Cerebral blood flow in man at high altitude. Role of cerebrospinal fluid pH in normalization of flow in chronic hypocapnia. Circ Res. 1966;19:274–82.
34. Hombein TF, Townes BD, Schoene RB, et al. The cost to the central nervous system of climbing to extremely high altitude. N Engl J Med. 1989;321:1714–9.
35. Litch JA, Bishop RA. Transient global amnesia at high altitude. N Engl J Med. 1999;340:1444.
36. Litch JA, Basnyat B, Zimmerman M. Subarachnoid hemorrhage at high altitude. West J Med. 1997;167:180–1.
37. Wilkes M, Simpson A, Knox M, Summers L. The kilimanjaro score for assessing fitness to fly paragliders at high altitude. High Alt Med Biol. 2013;14(3):304–7.
38. Terra M, Vloemans AF, Breederveld RS. Frostbite injury: a paragliding accident at 5500 meters. Acta Chir Belg. 2013;113(2):143–5.
39. Chipperfield M, Squires N. Paraglider survived in storm at 32,000 ft. The Telegraph 2007. http://www.telegraph.co.uk/news/worldnews/1542962/Paraglider-survived-in-storm-at-32000-ft.html. Accessed on Mar 2015.
40. Chech TV. Principles of water resources: history, development, management, and policy. 3rd ed. Wiley, Hoboker, NJ, United States; 2010. p. 60.
41. Feltracco P, Barbieri S, Galligioni H, Pasin L, Gaudio RM, Tommasi A, Zucchetto A, Trevisiol P, Ori C, Avato FM. A fatal case of anaphylactic shock during paragliding. J Forensic Sci. 2012;57(6):1656–8. doi:10.1111/j.1556-4029.2012.02187.x.

BASE Jumping and Wingsuit Flying Injuries

19

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19.1 BASE Jumping

BASE jumping is an extreme sport which involves parachuting from a fixed structure. Although experiences of parachute jumps from fixed objects were mentioned in Chinese literature two millennia ago and have been in recorded practice for centuries [1, 2], BASE jumping assumed the characteristics of a modern extreme sport in the early 1980s. During that time, one of the pioneers of modern BASE jumping was the filmmaker Carl Boenish who filmed the first BASE jumps made using ram-air parachutes from the El Capitan Cliff in Yosemite National Park, USA. He also coined the BASE acronym, summarizing the initials of the objects from which jumps are made: buildings, antennas, spans (bridges, domes, or arches) and earth (natural formations, usually cliffs). In the early years of BASE jumping, athletes used skydiving equipment with very few modifications including both a main parachute and a reserve, while single parachute systems representing today's equipment became available at the beginning of the 1990s [3]. The sport's participants have increased over the years but are still relatively few; on the basis of data from equipment manufacturers [4], it is estimated that there are around 3000 BASE jumpers in the world today [5]. Competitions have been taking place since the early 1980s with judging criteria which include accurate landings and acrobatics [4] despite the fact that BASE jumping, similarly to some of the most dangerous extreme sports, tends to discourage competitions since more fatalities could occur during official events as BASE jumpers try to push their limits in order to win.

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19.1.1 Equipment

BASE canopies originated from skydiving parachutes. Over the years, BASE equipment and jumping technique has evolved through a process of trial and error achieved mainly by analyzing the causes of suboptimal efficiency or malfunction of equipment after incidents (1), injuries or fatalities. In 1997, the Cliff Jumpers Association of America, an organization established by jumpers and manufacturers across the USA with the purpose of bringing the BASE jumping community together to overcome legal issues, set down a number of definitions, practices, and standards for this sport in the CJAA Guidelines [6]. The use of skydiving equipment was not recommended, while the use of BASE-specific equipment was encouraged.

Although they originate from skydiving parachutes, BASE canopies use high-strength lines, often have a tail pocket on the rear top skin of the center cell to stow the lines, and are much more strongly reinforced at certain points: the bridle attachment points, the lower surface, the leading edge, and along the most directly loaded parts of the ribs. This is due to the fact that BASE canopy openings are abrupt, hard, and forceful. The strength and positioning of load tapes are also designed to minimize failure in the event of object strike. Appropriate ram-air canopies for BASE jumping have a low aspect ratio, usually below 2.2:1. Aspect ratio is the relationship between the parachute's span and its chord (span/chord), and canopies with a low value are more predictable during the opening sequence and generate more drag. As a consequence, these canopies have a lower flight speed and a wide control range, two critical factors in tight or demanding situations.

Today in BASE jumping, limiting the equipment to a single parachute is considered safer. This is due to two factors. Firstly, the fall space of many jumps is minimal allowing no time to open a second parachute. Secondly, the addition of a reserve parachute involves various compromises in packing and fitting which may increase the risk of malfunction, in particular the risk that the two parachutes may become entangled [4]. BASE jumping requires the parachute to open rapidly, taking the jumper from free fall to canopy flight in the shortest possible time without injury or equipment damage.

Parachute deployment is initiated by releasing a pilot chute, a small round parachute which pulls the main canopy from the container. For each jump, jumpers should plan the speed and abruptness of opening by choosing the appropriate pilot chute size. In lower jumps, a larger pilot chute is necessary to create the required pull force to start the deployment at a lower fall speed. The way in which the canopy is packed affects deployment speed, so the packing needs to be adequate to the jumped object. If the opening is too fast, BASE jumpers may incur injury to their neck or internal organs [7]. If the opening is too slow, they may hit the ground before the canopy has had time to fully inflate.

As in skydiving, reefing devices are commonly used to slow and stage the opening sequences of canopies. This results in lower opening forces preventing the excessive deceleration forces at higher speeds which may damage the canopy or injure the athlete. One common reefing device is the *slider*, a small rectangular piece of fabric with grommets or rings at the corners through which the line groups pass. During deployment, it slides down from the canopy along the lines slowed by air resistance so that it may slow down the line spread and canopy inflation helping to prevent the lines from twisting (Fig. 19.1).

BASE jumping from lower objects often requires a rapid canopy deployment, and in these cases, the slider may be eliminated (*slider off* pack jobs) or limited in its effectiveness by packing the chute with the slider at the base of the lines (*slider down* pack jobs) [3, 8]. The *tail gate* is a reefing device which sequences the opening of the parachute. It forces the nose of the canopy to inflate first followed by the tail to minimize the risk of brake-line malfunctions. Very low objects (below 60 m/200 ft) require the canopy to open almost immediately on exit-

Fig. 19.1 Operation of the slider

ing, and an assisted deployment system is often used in these cases [3]. In an assisted deployment system, one end of the deployment chain is fixed to the exit point or held by a fellow jumper, so the deployment starts as soon as the jumper leaves the exit point, and there is no free fall involved. An assisted deployment system may consist of a *static line*, a break cord (or velcro) used to connect the canopy to an anchor point, or a *pilot chute assist*, a system where the pilot chute is held by a helper until the jumper reaches line stretch [6].

Bridles for BASE jumping are longer than those used in parachuting. The distance between the attachment (*pin*) and the pilot chute measures at least 2.7 m (9.0 ft). This length is necessary to generate a greater snatch force which is critical due to the low airspeed during BASE jumping deployments. It is also required to prevent the opening system (the pilot chute, in particular) being influenced by the wake turbulence behind the jumper during free fall. The use of ultralight fabrics combined with lightweight, low-profile containers has allowed the weight of the equipment used by BASE jumpers to be more than halved. Lightweight canopies are preferred by jumpers who spend most of their time jumping from higher cliffs or objects which require longer approaches as well as by wingsuit pilots or BASE jumpers who wish to have a low-profile container system.

19.1.2 Exiting

The terminal velocity of a skydiver in a belly-to-earth (face down) free-fall position is about 195 km/h (121 mph or 54 m/s) [9]. It represents the asymptotic limiting value of the acceleration process: 50 % of terminal velocity is reached after about 3 s and 90 % after 8 s, while it takes 15 s of free fall to reach 99 %. BASE jumping is characterized by the low altitude from which the fall starts, often less than 150 m above the ground, and by the proximity to the jumped object during flight. The shortness of the flight means there is insufficient time to reach terminal speed, and BASE jumpers operate at slower airspeeds due to the limited altitude. For this reason, while skydivers use the air flow to stabilize their position during their flights, BASE jumpers have much less aerodynamic control over their position in flight.

As a consequence, exits play a key role in BASE jumping. Body position at the moment of jumping determines the stability of flight in the first few seconds before the jumper achieves sufficient airspeed to enable aerodynamic stability (Fig. 19.2). In a short jump, a good exit helps to ensure a stable free fall and puts the athlete in the right body position for a good deployment, while a poor exit may negatively affect deployment. Also in a longer jump, a poor exit requires a lot of jumper skill and experience to get back to a good position. Instability at the moment of deployment places the jumper at high risk of chute malfunction, entanglement or *off-heading* canopy opening, an undesirable event where the parachute opens facing the object jumped from and sending the jumper toward the fixed object with a high risk of collision [4].

Fig. 19.2 An illustration of the exit point in base jumping and the transition into *tracking away* flight position (Photo: Ronen Topelberg. © Omer Mei-Dan 2016. All Rights Reserved)

19.1.3 Objects

As well as being technically complex, jumping from a building or a tower has legal implications, and BASE jumpers rarely obtain permission to jump from these objects. Owners of buildings or landing zones may occasionally allow authorized BASE jumpers access such as in the case of a BASE jumping event. The most popular example is probably the KL Tower BASE Jump, an annual 4-day event that usually takes place in September and sees numerous BASE jumpers leap from the open deck of the Menara Communication Tower, a 421-m (1381-ft) jump in Kuala Lumpur, Malaysia [10]. In addition to the legal implications, the risk of radiation and electrocution should be taken into account when considering a jump from an antenna. Spans are generally considered to be the safest kind of fixed objects for BASE jumping due to the increased airspace and the least number of obstacles to avoid during the fall. The Perrine Bridge in Twin Falls, Idaho, a sub 153-m (500-ft) bridge running north and southbound on Route 93, the main link between Twin Falls County and Jerome County, is the only man-made structure in the USA where BASE jumping is allowed year-round without a permit. This is the main reason for its worldwide popularity as a BASE jumping site [11]. BASE jumping is also allowed during Fayette County's "Bridge Day," held the third Saturday of every October at the New River Gorge Bridge, a 267-m (876-ft) high arch bridge over the New River Gorge near Fayetteville, West Virginia, in the Appalachian Mountains of the eastern USA [12]. Natural cliffs are very popular with BASE jumpers. They provide more flight time and usually the opportunity to reach near-terminal airspeeds to track away from the object [3] (Fig. 19.3).

However, some high cliffs ideal for BASE jumping are located in remote areas, far from medical assistance, and the difficulties associated with access for rescue services as well as the time required for the recovery of the victim in the case of an incident may increase the risk of fatalities.

Upon completing a jump from all of the four object categories (buildings, antennas, spans, and earth), a jumper may choose to apply for a "BASE number", which are awarded sequentially. BASE number 1 was awarded to Phil Smith of Houston, Texas, in 1981. As of December 2014, over 1850 BASE numbers have been issued [13].

19.2 Wingsuit Flying

Wingsuits are suits equipped with small wings of fabric between the legs and under the arms that enlarge the surface area of the human body

Fig. 19.3 BASE jump of the Basaseachic falls in Mexico, meter cliff (Photo: Yaron Weinstein. © Omer Mei-Dan 2016. All Rights Reserved)

Fig. 19.4 An exit of a wingsuit flight before the air fills in the wing's compartments. South Africa (© Omer Mei-Dan 2016. All Rights Reserved)

(Fig. 19.4). Ram-air technology which involves air being inserted under pressure between layers of fabric is used in the wings of these garments and allows flights at glide ratios (lift/drag) from 2:1 to 3:1 (2 and 3 m for every 1 m of loss in altitude, respectively) comparable to that of an open flying wing parachute [5, 14].

Achieving the optimal body position involves the athletes finding the best compromise between exposure of the greatest possible surface area to airflow, the best angle of attack for the cleanest possible airflow over the wingsuit surface, and the route required. A wingsuit flight may start from a skydiving drop aircraft or BASE jump exit point, and normally ends by deploying a parachute. At this point, the athletes usually unzip the arm wings allowing them to reach the steering parachute toggles and control the landing. In BASE jumping, the use of wingsuits makes objects jumpable that otherwise would not be, allowing pilots to fly down mountain slopes of various conformations along ridges or through canyons [5]. The development of high flight-glide ratio wingsuits has also allowed the introduction of a new style of flight called *proximity flying*. In this kind of flight, wingsuits are not used to glide away from the jumped object but rather to fly in close proximity to walls, a few meters above ridge lines or rock formations in order to better enjoy the speed and the surrounding landmarks [5]. Although the wing area offered by the wingsuits has gradually increased over the years resulting in more lift and an earlier start to the flight, it also requires more experience and training to master when used at lower air speeds.

19.3 Injuries

Soreide et al. reviewed records of 20,850 jumps from 1995 to 2005 at the Kjerag Massif in the Lysefjorden (Rogaland County, Stavanger) on the southwestern coast of Norway and reported a total of 82 adverse events [15] requiring the involvement of a helicopter and climbers in rescue in 27 and 8 cases respectively. In this series, an injury rate of 1/254 jumps (0.4 %) including minor injuries was found. Most of the injuries were minor such as concussions and sprained ankles or knees, while a few were moderate including an ankle fracture and a head concussion requiring overnight observation. However, it was pointed out that this location, despite being a world-renowned site for legal BASE jumping activity, is not representative of BASE jumping as whole since the Kjerag jumping zone is relatively forgiving. It is a 1000-m high cliff (about 3300 ft) that allows jumpers to reach high airspeeds, stabilize their body position, and move away from the wall before opening the canopy, and it has a clear landing area [4].

According to the literature, BASE jumping seems to have an injury rate around ten times higher than skydiving [4]. In a study of severe and catastrophic injuries in a heterogeneous group of 102 international BASE jumpers evaluated between 2006 and 2010, Mei-Dan et al. [16] reported an injury rate for severe injuries of 1/500 jumps (0.2 %). Out of 39 reported injuries, to 29 different jumpers, 61 % ($n=24$) were to the lower limbs, 20 % ($n=8$) to the spine, 18 % ($n=7$) to the chest, and 13 % ($n=5$) to the head. The injuries included 44 fractures, three cases of polytrauma requiring admission to an intensive care unit (requiring advanced trauma life support and including injuries such as: pneumothorax, head injury and cervical spine injury), two concussions, one Achilles tendon tear, and one major head laceration. With regard to fractures, 25 (56.8 %) were to the lower limbs, especially the ankle and foot (45.5 % of all fractures; $n=20$), eight (18 %) involved the upper limbs, six (13.6 %) the spine, and five (11.3 %) the ribs [16].

BASE jump canopies are designed to open more quickly than skydiving parachutes and may, as a consequence, exert strong compression on the chest through the harness. Brugger et al. [7] reported the case of an acute ST-segment elevation myocardial infarction related to thrombotic occlusion of the proximal left anterior descending artery resulting from the blunt chest trauma caused by the abrupt opening of the parachute during a 300-m (91.5-ft) high cliff edge jump into the valley of Lauterbrunnen, Stechelberg, Switzerland. The patient, a 35-year-old male jumper, had no previous history of cardiovascular diseases.

Adverse events are more common among untrained or inexperienced jumpers, and miscalculation of weather conditions is a major cause [15]. Bad judgment may dramatically increase the risks in BASE jumping. In particular, it may be dangerous to jump from illegal BASE jumping objects such as skyscrapers, public buildings and antennae as many jumpers are unaware of the risks of such sites. Limited time availability for the jump presents an additional risk factor. Similarly, jumps performed during dusk or dawn or even at night when visibility may be suboptimal have an increased risk potential.

Mei-Dan et al. [16] found that the injury rate per jump was higher at the beginning of the jumper's career and peaked at between approximately 90 and 130 jumps. Within that range, jumpers have probably acquired enough experience to feel confident and progress to less forgiving objects, aerobatic jumps or wingsuit BASE flights.

19.4 BASE Jumping Fatalities

The BASE Fatality List is a chronological list of fatalities of BASE jumpers since 1981. It was originally written and maintained by the BASE jumper Nick DiGiovanni. Fellow BASE jumpers Mick Knutson and Brad Patfield continued it from 2007 onward, and then the database was moved to BLiNC Magazine [17]. No data was lost or omitted during administrator transitions according to Knutson's assessment [5]. Two hundred and sixty five BASE jumping fatalities have been documented from 1981 to the present (July 25, 2015) [17].

Westman et al. [1] analyzed data on 106 fatal injury events reported worldwide in the period 1981–2006 retrieved from the BASE fatality list. Based on Mæland's [18] appraisal of 700 active BASE jumpers in 2002 and 12 fatalities worldwide the same year, the authors estimated a fatality rate of one fatality/60 participants/year (1.7 %), a rate 40–65 times higher than that of skydiving. In the same study, Westman et al. found that an important factor in determining fatalities was free-fall instability often associated with deployment failures. It was then possible to trace the dynamics of the fatalities to 98 of the cases (Fig. 19.5).

Among these, 36.7 % ($n=36$) of the fatalities were caused by impact with the ground (or water), 54 % ($n=53$) by cliff strikes, 4 % ($n=4$) by building strikes, 3 % ($n=3$) by drownings following water landing, and 2 % ($n=2$) by collisions with obstacles other than the jumped object. In the same study, insufficient parachute inflation was the main cause of 58 fatalities (59.1 %). Other reported causes of fatal events were wire strike and parachute deflation ($n=2$; 2 %) and parachute collision and deflation ($n=1$; 1.02 %). Insufficient parachute inflation was a consequence of insufficient pilot chute inflation in 24 cases (41.3 %), ineffective static line in three cases (5.2 %), and locked containers in two cases (3.4 %), while another two cases (3.4 %) were caused by bridle being snagged around the jumper or the canopy equipment making the athlete unable to extract the parachute from the container (*bridle jam*).

In three fatal events following insufficient parachute inflation, the jumper opened a reserve. In two of these cases, death was a consequence of impact caused by insufficient reserve inflation and by a reserve inflated with line twists, while in the remaining case, the reserve chute inflated, but death was caused by drowning following a water landing [1]. However, modern BASE rigs no longer contain a reserve as explained above. In ten cases (10.2 %), free-fall acrobatics (including deliberate falls in a standing position) were a main factor because the failed acrobatics were often followed by a failure of proper parachute deployment. In the same study, unintentional free-fall instability was reported in 26 cases (26.5 %) and was often followed by deployment failure or off-heading parachute inflation. An off-heading opening is an undesirable event where the parachute opens facing the object jumped from and pulling the jumper into said object. Causes for off-heading openings are believed to be multifactorial and may include poor body position at the time of deployment. It is an ongoing debate as to whether *reefing devices* used in jumps where high *sub-terminal* fall speed is reached may also favor *off-heading openings* [1]. In jumps with about 3–9 s of free fall, high velocity is reached and a reefing device is necessary, but terminal velocity has not yet been achieved, and the momentary lower surface inflation due to the reefing device could potentially promote off-heading opening [1].

Soreide et al., in their study from a single site in Norway over an 11-year period [17] reported nine fatalities (0.04 % of all jumps) and found a fatality rate of 1/2317 jumps. Of these nine fatalities, eight occurred on scene. Most of the fatalities were caused by severe head injuries of which four were classified as "not survivable" [19] while six presented five or more serious injuries. Even survivable injuries may become fatal in some extremely challenging environments where certain BASE sites are located. In the study by Soreide et al. [17], one jumper survived the impact but remained stranded on a ledge at a height of 300–400 m (around 900–1300 ft), due to the difficulty of being reached by rescue services. The rescue attempt was also hampered by poor weather conditions. The jumper died following a second fall which may have occurred in an attempt to open the reserve or because of a loss of consciousness due to blood loss from serious pelvic and femoral fractures.

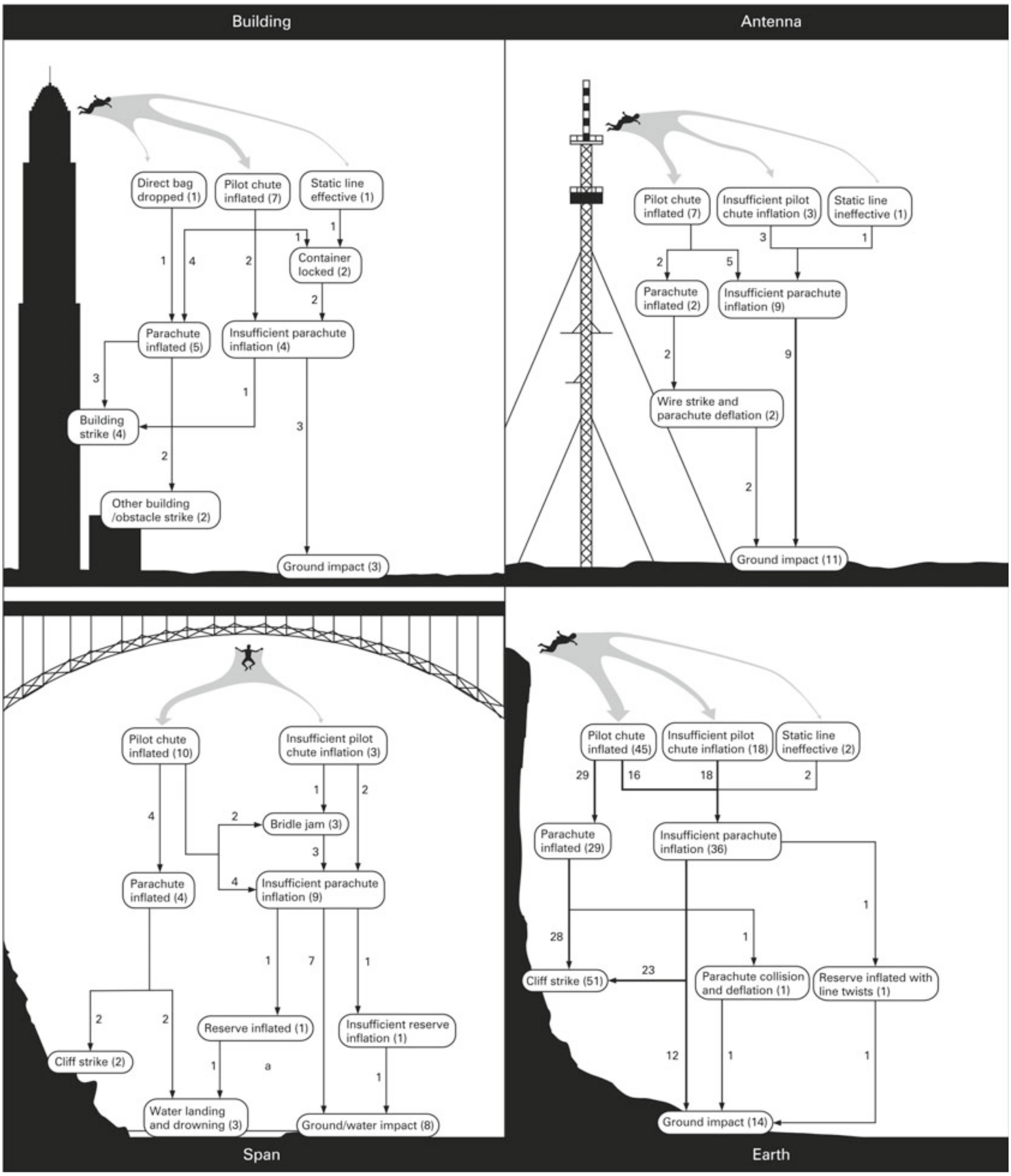

Fig. 19.5 Events cascade leading to BASE jumping fatalities reported in the BASE fatality list during the period 1981–2006. The *numbers* in the boxes and on the *arrows* show the number of events (Reprinted with permission from Westman et al. [1])

The use of drugs or alcohol before jumping may be extremely hazardous. Wolf and Harding [20] reported the case of a 48-year-old skydiving instructor and experienced BASE jumper who died after jumping from the 1249-ft antenna of a radio broadcast tower in southwest Florida. The cause of the crash was attributed to a prolonged delay in opening the parachute. The authors stated that alcohol consumption may have played a role in the incident.

19.5 Wingsuit-Related Fatalities

Wingsuit-related fatalities are growing with the spread of this variant of BASE jumping. Mei-Dan et al. examined 39 wingsuit BASE jumping deaths from 1981 to 2011. In the period between 2002 and 2007, wingsuit-related deaths accounted for 16 % of all BASE jumping deaths. This number rose to 49 % between 2008 and 2011 reaching 87 % in 2013 [5]. A contributing factor to this increase in wingsuit-related BASE fatalities is probably the introduction of “proximity flying”. A flight path miscalculation while flying a wingsuit may cause a high-speed collision with the ground or jumped object.

Of the 39 BASE-related wingsuit fatalities reported, 49 % ($n=19$) were the consequence of cliff strikes, 46 % ($n=18$) were due to ground impact, 3 % ($n=1$) were caused by a building strike, and, in one case, the data was insufficient to classify the fatal event cause. Cliff or ground strikes may be the consequence of parachute malfunction due to an unstable wingsuit flying position at the time of deployment. Among the 39 reported fatalities, 53.5 % ($n=17$) were attributed to wingsuit glide path miscalculation, especially in “proximity flying”; 17.9 % ($n=7$) to exit complication; 12.8 % ($n=5$) to pilot chute complication, mainly caused by air turbulence created above the jumper by the wingsuit; and 2.5 % ($n=1$) to wingsuit equipment failure (torn fabric in flight), while in 23 % ($n=9$) of the cases, the cause was unknown [5]. Since BASE jumping is a technically demanding sport, limited experience seems to be a contributing factor as in the majority of extreme sports.

19.6 Prevention

19.6.1 Protective Clothing

Protective gear includes padding and armor created to protect many parts of the body, often made from hard plastic materials and closed-cell foam. Recently, flexible protective clothing featuring compartments filled with “intelligent molecules” (which flow freely in normal conditions but block together to protect the body if shocked) have also been introduced [3]. The use of a helmet rated for air or motorcycle sports is recommended. Camera helmets usually in carbon and fiberglass designed for skydiving use have a reduced profile and weight but provide inadequate protection in the case of a BASE jumping impact [3]. Many different types of footwear may be suitable for the purpose including paragliding boots, but the main requirement is a lack of eyelets or protrusions which could catch the lines.

19.6.2 Physical Training

Risk management plays a key role in BASE jumping and wingsuit flying. Experienced jumpers are familiar with the evaluation of many factors including weather, environmental and technical aspects, and they spend a lot of time preparing their jumps in detail. Experienced skydivers generally have the attributes of balance and body awareness required for an adequate BASE jumping exit, but the “dead air exit” is specific to BASE jumping and requires specific training. Exiting from a fixed object may be simulated by jumping from a springboard above a pool or skydiving from hot air balloons. Given that balloons move with the wind however, the initial airflow in these conditions may be even less than in BASE jumping [1]. A specific training regime to improve balance and spatial awareness is, therefore, of particular importance in BASE jumping. This may include taking high dive classes and using balance tools to improve coordination [3].

Moreover, since not all exit points are accessible by vehicles or elevators, jumpers often need to trek long distances carrying their equipment and reach high altitudes before jumping. After these struggles, jumpers need to have adequate physical and mental energy to perform well in the jump and be able to react promptly to any unexpected events. A lack of adequate fitness and the resulting fatigue with its potential to reduce reaction time and the ability to concentrate could become an additional risk factor for incidents (1) in some situations. For these reasons, high levels of strength and cardiovascular fitness are strongly recommended for BASE jumping athletes.

References

1. Westman A, Rosén M, Berggren P, Björnstig U. Parachuting from fixed objects: descriptive study of 106 fatal events in BASE jumping 1981-2006. Br J Sports Med. 2008;42(6):431–6. doi:10.1136/bjsm.2008.046565. Epub 2008 Jun 3.
2. Lucas J. The silken canopy: a history of the parachute. Revised edition. Shrewsbury: Airlife; 1997.
3. Gerdes M. The great book of base. BirdBrain Publishing, Planet EARTH, www.base-book.com; 2010. p. 1–71.
4. Mei Dan O. BASE jumping. In: Mei Dan O, Carmont MR, editors. Adventure and extreme sports injuries. London: Springer; 2013.
5. Mei-Dan O, Monasterio E, Carmont M, Westman A. Fatalities in wingsuit BASE jumping. Wilderness Environ Med. 2013;24(4):321–7. doi:10.1016/j.wem.2013.06.010.
6. Cliff Jumpers Association of America. General guidelines. 1997:1–17. http://www.crmojo.com/adobepdf/cjaaguidlines.pdf.
7. Brugger N, Saguner MA, Zbinden S, Khattab AA. LAD dissection following parachute belt trauma during BASE jumping. Int J Cardiol. 2012;159:25–6.
8. BLiNC. Everything you ever wanted to know about BASE-Jumping. http://www.blincmagazine.com. Accessed on July 2015.
9. Westman A, Äng BO. Validation of a free fall acrobatics intervention protocol to reduce neck loads during parachute opening shock. BMJ Open Sport. doi: bmjsem-2015-000045.
10. KL Tower Jump. KL Tower International Jump Malaysia. http://www.kltowerjump.com/. Accessed on March 2015.
11. Boutwell J. Tips for jumping the Perrine Bridge Skydiving magazine. 2007;(2). http://www.skydivingmagazine.com. Accessed on March 2015.
12. Bridge Day Commission. Bridge Day 2015. Vertical Visions LLC. 2015. http://www.bridgeday.info/. Accessed on March 2015.
13. BASENumbers.org. http://www.basenumbers.org/. Accessed on March 2015.
14. Cordia J, Bartels S. Fallrates and glide ratios. flylikebrick.com. easyJet airline company ltd. http://www.flylikebrick.com/articles/flb_fallrate_vs_glideratio.pdf. Accessed on March 2015.
15. Soreide K, Ellingsen CL, Knutson V. How dangerous is BASE jumping? An analysis of adverse events in 20,850 jumps from the Kjerag Massif. Norway J Trauma. 2007;62(5):1113–7.
16. Mei Dan O, Carmont MR, Monasterio E. The epidemiology of severe and catastrophic injuries in BASE jumping. Clin J Sport Med. 2012;22(3):262–7.
17. BASE fatality list. blincmagazine.com. http://www.blincmagazine.com/forum/wiki/BASE_Fatality_List.
18. Mæland S. Basehopping—nasjonale selvbilder—sublime opplevelser. Norsk Antropologisk Tidsskr. 2004;1:80–101. http://www.faa.gov/regulations_policies/handbooks_manuals/aircraft/media/faa-h-8083-17.pdf.
19. Baker SP, O'Neill B, Haddon Jr W, et al. The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care. J Trauma. 1974;14:187–96.
20. Wolf BC, Harding BE. Patterns of injury in a fatal BASE jumping accident. Am J Forensic Med Pathol. 2008;29:349–51.

Surfing and Skimboarding Medicine

20

Kenneth S. Taylor and Emanuel A. Elias

20.1 Introduction

The sport of surfing began many centuries ago in the South Pacific region. It was an integral part of Hawaiian culture, practiced by both commoners and royalty. Its practice declined during the 1800s when it was discouraged by missionaries to the islands, until a revival began in the early twentieth century. Surfing is now enjoyed as a recreational sport by over 18 million people worldwide of all ages [1]. In addition, surfing competitions exist on the primary and secondary school, college, and professional levels (Figs. 20.1, 20.2, 20.3, and 20.4).

Stand-up paddle surfing is growing in popularity. It is a variant of surfing, in which the surfer paddles to move through the water, and glides or rides waves (Fig. 20.5) while standing on a surfboard.

With the advent of newer technological means of creating rideable waves in pools and indoor arenas, surfing has expanded from coastal and great lake communities to inland areas and even cruise ships.

Surfing is an intermittent sport with paddling accounting for 50 % of the activity, limited motion/waiting for suitable waves for 40 %, and 5–10 % spent actually riding the wave. Surfers possess a high level of aerobic fitness and peak VO_2 values are comparable to other upper-body endurance-based athletes. There are cyclical bouts of low-intensity activity soliciting aerobic metabolism intermixed with high-intensity exercise utilizing both aerobic and anaerobic metabolism [2]. As a highly active water sport, those participating in surfing are prone to a unique constellation of acute and chronic conditions which physicians caring for these patients should be aware. This chapter will review some of the more frequent illnesses and injuries seen in these athletes with a discussion of relevant preventive strategies.

20.2 Trauma

Surfboard riders are prone to a multitude of acute and chronic conditions (Table 20.1).

Several authors have presented retrospective studies on the frequency and type of injuries incurred by surfers. Lowden et al. published one of the first studies on the prevalence of injuries among 346 Australian surfers which required either medical attention or days lost from surfing [3]. They reported that lacerations were most frequent, representing 41 % of all injuries. Most lacerations were to the head, mainly to the skull, with lower extremity lacerations next most frequent. The second most common injury type was dislocations, sprains, and strains which

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Fig. 20.1 Performing a cutback. Surfer: Kenneth Taylor. El Salvador

Fig. 20.2 Dropping into an overhead wave. Surfer: Kenneth Taylor. Spot: Blacks Beach, San Diego (CA)

represented 35 % of all injuries. Other injuries included skull and body fractures, contusions, and tympanic membrane perforations. Overall, 3.5 injuries per 1000 surfing days were reported in their study.

In 2002, Nathanson published a larger study of 1348 surfboard riders [1]. They also found lacerations to be the most common injury, but with head and neck lacerations to be equally as prevalent as lower extremity ones. Contusions, sprains, and fractures were also seen. The majority of contusions affected the trunk and lower extremity. Sprains were most reported in the lower extremity, with knee injuries most often seen. The majority of fractures reported by Nathanson et al. were to the head and neck. Of note, both Lowden and Nathanson found a higher level of injury severity in more advanced surfers, who often engage larger waves in more extreme conditions (Fig. 20.6).

The large majority of injuries reported in both studies were from contact with a surfboard,

Fig. 20.3 Top turn. Surfer: Kenneth Taylor. Indonesia

Fig. 20.4 Island surf. Surfer: Kenneth Taylor. Indonesia

usually the rider's own board. The rail and fins of the board accounted for most of the injuries seen. The seafloor is another common source for injury, responsible for 17 % of injuries in the Nathanson study. Surfing over coral reefs versus sand is a significant risk for sea floor injuries [1] (Fig. 20.7).

Additional risks involved with surfing include injury leading to either drowning or hypothermia should the surfer not be able to safely return to shore. Lacerations have the added potential of becoming infected with seaborne organisms and should be treated for *Vibrio* and *Pseudomonas*, along with the more common *Staphylococcus* and *Streptococcus*.

Nathanson published another study in 2007 on injuries during 16,657 surfer heats observed over 32 surfing competitions worldwide from 1999 to 2005 [4]. They found an injury rate of 13 per 1000 h of competitive surfing. Professional competitions had higher rates of injury in comparison to amateur competitions; however, professional contests were held in larger surf, were longer in duration, and occurred more often over a hard

Fig. 20.5 SUPing in Cape Verde. Surfer: Airton Cozzolino (Photo courtesy of Claudio Marosa)

Table 20.1 Summary of common injuries seen in surfboard riders

Acute injuries	Chronic injuries
Head lacerations	Repetitive motion injuries to back, shoulders, knees, neck
Lower extremity lacerations	Auditory exostoses
Lower extremity sprains, especially knee	Otitis externa
Contusions	Pterygium
Concussion	Recurrent cellulitis
Marine envenomation	
Tympanic membrane rupture	

bottom, as opposed to sand. Sprains and strains were most commonly seen, followed by lacerations, contusions, and fractures. The lower extremity was the most injured location, with knee sprain/strain being the most common injury pattern overall. The majority of injuries were due to impact with the surfboard, and most injuries occurred during an unsuccessful takeoff, followed by turning maneuvers.

Preventive safety measures can help reduce the frequency and severity of injury. Surfing helmets are available and their widespread use could help reduce the number of head lacerations and fractures [5]. Nathanson, however, reported that only 8 % of surfers in their survey used helmets [1]. Rubber guards on the board's nose and soft-edged or rubber-guarded fins would also help reduce the number of lacerations and are thought not to alter surfboard dynamics to any appreciable degree. Their use as reported by Nathanson is limited, with 40 % of surfers reported using nose guards and only 5 % of surfers having soft-edged fins [1]. Protective eyewear specifically designed for surfing is available from several manufacturers and may afford both protection from UV rays and orbital trauma.

The use of a board leash in preventing injury is controversial. Leashes do seem to have reduced the number of accidents involving loose boards hitting other surfers. Leashes also provide the downed surfer with access to a floatation device in the event of serious injury. But by keeping the board in close proximity to the surfer, leashes may increase the risk of board-induced injury. In addition, board recoil from the leash is another mechanism for injury to the surfer. Two articles of surfboard-related ocular trauma implicate the board nose as the common mechanism of injury, with Kim et al., implicating leash recoil as one causative factor [6, 7]. Leashes are sold in varying lengths. Longer leashes may decrease recoil injury, with the consequence of increased risk of injury to others.

A recent addition to potential injury associated with surfing has been coined surfer's

Fig. 20.6 Barreling wave, nearby surfer bails his board (*yellow board*) which gets broken in half by the wave

Fig. 20.7 Facial lacerations and contusions from contact with reef

myelopathy by Thompson et al., who reported nine cases occurring between 1998 and 2003 in Hawaii [8]. Since then, several case reports and case series have been published, describing very characteristic clinical presentations and features among patients with surfer's myelopathy [9–18]. It seems to affect first-time surfers or those learning the sport. It appears to be a nontraumatic paraparesis/paraplegia that may be associated with hyperextension of the lower thoracic, upper lumbar segments in an untrained surfer. No injury was noted during surfing, but most patients complained of mild mid- to low back pain, lower extremity weakness, and urinary retention. A retrospective review of MR findings in 23 cases of surfer's myelopathy by Nakamoto et al. demonstrated central T2 hyperintense signal abnormalities in the spinal cord extending from the midthoracic region to the conus in all cases. These findings were associated with cord expansion and conus enlargement, all seen within 24 h of symptoms onset. However, MR findings did not correlate with symptom severity or clinical improvement [19]. Although most patients achieved significant improvement or resolution, several cases of complete paraplegia have been noted. The pathophysiology is possibly due to a secondary ischemic event from hyperextension and spinal cord traction, resulting in spinal cord injury and the abnormal signal findings of the lower thoracic/upper lumbar segments of the spinal cord seen on MRI. While not enough is known of this disorder to make definitive recommendations on prevention, swimming and surfboard paddling for endurance and strength gains as well as flexibility training may reduce the incidence of this malady, particularly since it does not appear to affect experienced surfers.

Surfing like most other sports is not immune to overuse injuries. The overhead nature of paddling is similar to swimming. Shoulder impingement syndrome, acromioclavicular arthrosis, and rotator cuff strains are common to surfers. Treatment is similar to that seen in other sports and includes activity modification, rotator cuff/periscapular strengthening, injections, and arthroscopic surgery for refractory cases or complete cuff tears. Prevention is geared toward a strengthening and consistent paddling regimen to maintain adequate strength and fitness [2].

Neck and lower back pain are common complaints of surfers. Degenerative disk and joint disease account for a fair amount of these complaints, particularly among aging surfers. Surfing has been implicated in a number of cases of spondylolysis and spondylolisthesis due to its repetitive hyperextension of the lumbar spine [2].

Spine trauma in the cervical spine is of particular concern because of the potential for central cord syndrome (CCS). Over 50 % of these injuries occur in older surfers particularly those with preexisting spondylosis [20]. The mechanism of injury was similar with nearly all of the injuries caused by hitting the ocean floor (75 %) resulting in neck hyperextension [21]. Injuries usually occur in the lower cervical spine and can result in burst fractures and complete spinal cord injuries.

20.3 Illnesses

20.3.1 Marine Envenomation

Interaction with other sea life is an inevitable part of ocean sports. Marine animals caused 3 % of reported injuries in the study by Nathanson. The more frequently encountered life forms which cause harm to surfers are the free-floating coelenterates, stingrays, and coral reefs. While clinical presentation may vary, certain general treatment principles apply to any type of marine envenomation.

First, most marine envenomations become infected [21]. Common organisms include *Staphylococcus*, *Streptococcus*, and *Vibrio* species. Special culture medium is needed for growing marine organisms, and the lab should be alerted if there are concerns for these. Broad-spectrum empiric coverage is warranted, and either third-generation cephalosporins or fluoroquinolones are good choices to treat *Vibrio* species. Lacerations should be allowed to heal secondarily or, if necessary, by delayed primary closure. Second, retained foreign bodies should be considered in most envenomations. Depending on the mechanism of injury and level of clinical suspicion, investigation of a retained foreign body can be done through wound exploration or appropriate radiographs. Tetanus prophylaxis should be given if the patient's immunity is not up-to-date.

Fig. 20.8 Jellyfish stings

20.3.1.1 Coelenterates

Coelenterates are invertebrate animals and can be either free floating or sessile. Surfers are more apt to encounter free-floating coelenterates such as the true jellyfish, box jellyfish, and Portuguese man-o-war. These animals have a main body and multiple dangling tentacles with numerous venom-filled cells called nematocysts. Nematocysts inject their toxins subcutaneously in response to either chemical or mechanical stimuli. Local symptoms of nematocyst envenomation include burning pain, erythema, edema, urticaria, and bullae formation, all which may lead to skin necrosis (Fig. 20.8). Systemic effects of the toxin can damage respiratory, cardiovascular, gastrointestinal, renal, musculoskeletal, neurologic, and ocular organs.

Initial treatment involves preventing further toxin release by removing any remaining tentacles or other animal parts. Larger animal parts can be carefully removed with forceps or gloves. No consensus exists as to the best method of inactivating

Table 20.2 Summary of study results conducted to evaluate different treatment strategies to reduce pain associated with jellyfish stings

Study	Nematocyst type	Treatment	Findings
Hartwick et al. [22]	Chironex (indo-pacific box jellyfish/sea wasp)	Methylated spirits	Released toxin
		Ethanol	Released toxin
		Urine	Released toxin
		Acetic acid	Prevented toxin release
		Vinegar	Prevented toxin release
Burnett et al. [23]	Chrysaora (sea nettle)	Vinegar	Caused nematocyst rupture
	Chrysaora	Baking soda	Prevented toxin release
	Physalia (bluebottle/Portuguese man-o-war)	Vinegar	Prevented toxin release
	Physalia	Baking soda	Allowed toxin release when chemically stimulated
Exton et al. [24]	Physalia	Cold packs	Decreased pain
Thomas et al. [25]	Carybdea (Hawaiian box jellyfish)	Cold packs	No pain relief
		Hot packs	Minimal pain relief
Nomura et al. [26]	Carybdea	Hot water immersion	Decreased pain compared to either vinegar or papain

nematocysts and reducing pain. Various treatments recommended by published and anecdotal sources include cold packs, heat application, or irrigation with a multitude of liquids. Study results are conflicting due to the variety of study designs and jellyfish species used (Table 20.2).

Fresh water or vigorous rubbing is not recommended since these may induce further nematocyst discharge [27].

Further treatment of pain and dermatitis includes antihistamines and either oral or parenteral analgesic. Systemic symptoms can appear many hours after exposure and duration of monitoring is usually based on severity of clinical presentation. Antivenin for the box jellyfish is available and should be used if envenomation from this animal is known or suspected. Additionally, clear return precautions and parameters are warranted after discharge from medical care. Prevention strategies include avoiding areas where high numbers of nematocysts have been reported. Wet suits may thwart some envenomations by preventing the toxin from reaching the skin, although stings through a wet suit have been seen.

20.3.1.2 Seabather's Eruption

An interesting type of envenomation occurs with exposure to the larvae form of certain types of coelenterates. Known as seabather's eruption, this intensely pruritic rash is thought to represent a hypersensitivity reaction to the larval toxin. It has been reported most often on the Eastern coast of the USA, the Caribbean, and as far north as Bermuda [28]. Rossetto et al. reported 38 cases in the southern region of Brazil [29]. It is thought that as the larvae get trapped in the swimwear, nematocysts discharge toxin. Further toxin release has been reported to occur when the bather then tries to rinse in fresh water [28].

Seabather's eruption presents as an urticarial maculopapular rash found in the areas of the body covered by the bathing suit. The rash can appear while the patient is in the water, or up to one and a half days later. The rash can last anywhere from 2 to 28 days, with most reactions resolving in 1 or 2 weeks [30]. Systemic symptoms may include fever, nausea, vomiting, and headache and occur most often in children [30]. Initial treatment can involve the topical application of substances in Table 20.2. Further treatment is symptomatic and may include topical corticosteroids, oral antihistamines, and oral steroids for severe cases. Burnett reports that oral thiabendazole has also been efficacious [31]. The bathing suit should be thoroughly cleaned as larvae can persist and reenvenomate at a later time.

Fig. 20.9 Sea urchin spines in foot are treated with immersion in hot solution containing acetic acid

20.3.1.3 Stingrays

Stingrays are commonly found in coastal waters of the USA. They are bottom-dwelling creatures which are usually encountered while surfers are entering or exiting the water in shallow, sandy areas. Their sting is provided by a sharp ensheathed spine located in their tail. This spine can penetrate wet suits and booties. These stings usually involve the lower extremity and present with pain out of proportion to the wound appearance. Wounds can be either punctures or lacerations. Pieces of the sheath or spine may be present. Recommended initial treatment is hot water immersion to inactive the heat-labile toxin. Retained animal product should then be excluded by either wound exploration or radiographic examination. Prevention consists of avoiding areas and times of day with known higher concentrations of stingray. Also recommended is shuffling one's feet while walking through the shallow sand. This alerts stingrays as to human presence whereby they scatter and do not get stepped on directly. Additionally, having larger numbers of surfers or bathers around also discourages stingrays from congregating, thus decreasing possible exposure.

20.3.1.4 Corals

Coral reefs are common sources of surfing-related lacerations. Because of the variety of plant and animal species found on these reefs, coral envenomation usually consists of toxin from multiple sources, including sea urchins and sea cucumbers. Coral lacerations usually present with pain, pruritus, and erythema (Fig. 20.9). The area should be irrigated and debrided if necessary. Acetic acid has been recommended for stinging pain associated with coral envenomation [32]. These wounds tend to heal slowly and may need antibiotic therapy such as fluoroquinolones to completely heal.

20.3.2 Otologic Issues

20.3.2.1 Auditory Exostoses

Auditory exostoses are bony outgrowths which arise from the temporal bone and protrude into the ear canal. Although not definitively proven, it is generally accepted that exostoses form as a response to chronic cold water exposure. Water less than 65 °F (18.5 °C) is reportedly needed for exostoses to form [33]. Kroon has demonstrated that cold-water surfers are at higher risk for developing exostoses [34]. Auditory exostoses are usually asymptomatic, but can present with conductive hearing loss, frequent ear infections, and occasionally pain. They are usually found bilaterally and multiple exostoses can usually be seen in a single ear canal.

The presence and severity of auditory exostoses has been shown to be directly correlative with the amount of time spent in the water. In 1996, Deleyiannis published a study of 21 Oregon surfers [35]. They reported a higher prevalence of exostoses in surfers with more years of participation and in those who surfed more times a year. Wong reported data from 307 professional surfers [36]. They found that as the number of years surfed increased, the prevalence and degree of severity of exostoses also increased. Along with their cold water data, Kroon also validated the results of Wong and colleagues.

The consistent use of earplugs may help prevent exostoses from forming. Even with the high prevalence of exostoses, only 17 % of surfers in Nathanson's study reported earplug use. The only treatment for exostoses is surgical, and this is usually reserved for severe, symptomatic cases. Unless cold water is avoided or earplugs are used, exostoses may recur postoperatively and necessitate reoperation.

20.3.2.2 Otitis Externa

Multiple factors predispose surfers to recurrent bouts of otitis externa. Most otitis externa is caused by damage to the external auditory canal from stagnant water in the canal. Any water sport including surfing will encourage prolonged moisture in the ear. Trauma to the thin epithelial lining by foreign bodies or high pressure can also contribute to infection. Trauma, chronic exposure to moisture, and exostoses make otitis externa a common ailment among surfers.

Common infectious organisms include *Pseudomonas aeruginosa* and *Staphylococcus aureus*. Fungi such as *Aspergillus* and *Candida* can also contribute. Most otitis externa can be empirically treated with topical antibacterial drops containing quinolones, neomycin, polymyxin B, or aminoglycosides. Some preparations contain hydrocortisone which can help reduce inflammation. Treatment is usually for 5–7 days, although some cases may need treatment up to 2 weeks [37]. Systemic antibiotic therapy is recommended for persistent cases, if otitis media is also present, or if spread beyond the ear canal is suspected. Antifungal treatment is indicated when fungal infection, more commonly seen in diabetic patients, is confirmed either microscopically or by culture. For patients with frequent bouts of otitis externa, a discussion of preventive strategies is warranted. Such options include the use of earplugs while in the water or the routine otologic administration of isopropyl alcohol/acetic acid mixtures to help dry the ear canal after surfing.

20.3.2.3 Tympanic Membrane Rupture

Tympanic membrane (TM) rupture usually occurs when either the surfer is struck by a strong wave directly in the head, or the surfer contacts the water surface with sufficient force after a fall. Lowden and Nathanson report that TM rupture represented 6 and 7 % of all injuries in their studies, respectively [1, 3]. TM rupture can present with ear pain, conductive hearing loss, tinnitus, vertigo, and bloody otorrhea [38]. It is diagnosed on otoscopic exam. Most ruptures of the tympanic membrane will heal spontaneously. Antibiotic therapy is only indicated if concomitant infection is present [39].

The patient should be counseled to keep any foreign material, including water, out of the ear. This usually means that the patient should avoid surfing until the perforation is healed. If necessary, molded earplugs can be used to keep water out during the healing process [28]. Like most otologic injuries, the incidence of TM rupture can be prevented by wearing earplugs. A helmet may also provide additional protection.

20.4 Skimboarding

Skimboarding is a beachside sport that started among the lifeguards of Laguna Beach, CA, in the late 1920s. Gaining steady momentum in activity in the 1960–1980s among beachgoers and vacationers, skimboarding has enjoyed increased popularity in recent years with the advent of professional tours and the manufacturing of professional-quality skimboards [40].

Skimboarding is performed with the rider running with the board from the beach toward the water edge, throwing the board down onto 1–2 inches of water, and then jumping onto the board. The rider may then continue “sand skimming” by gliding over the thin layer of water at the ocean interface, or transition to “wave skimming” by gliding off of the beach and into an oncoming wave. Unlike surfing, where buoyancy is required for surfboard design, skim boards rely on hydroplaning by compressing the water between the board and underlying sand at an upward angle to achieve lift and to maintain speed. Average skim boarders can reach speeds up to 15 mph [41].

Fractures represent the majority of injuries among skim boarders, most commonly occurring at the lower extremities as demonstrated by the available literature. “Skimboarder’s Toe” was coined by Donnelly, who studied MRI findings of the metatarsophalangeal joint in two adult skim boarders who sustained hyperdorsiflexion injuries with findings of extensor expansion disruption and dorsal soft tissue edema [40]. Williams published a case series of skimboarding injuries over 5-month period, with 8 of the 10 cases having fractures in the lower extremities [42]. A retrospective review of 80 patients with skimboard injuries over a 53-month period conducted by Merriman found fractures to be the most common injury (73.4 %), followed by soft tissue injuries (19 %) and lacerations (7.6 %). Lower extremity injuries occurred in 63.8 % of patients, with the ankle being the most injured site [43]. Another study with 61 patients showed similar results, with fracture representing 93.4 % of the injuries, with almost half of the patient incurring twisting injuries at the lower extremity. The most common injury was a fracture at the ankle (37.7 %), followed by distal radius fractures (34 %) [41]. Three cases of spinal cord injuries have also been reported in the literature, with injuries sustained when the riders fell, head first, off of their boards and into the shallow water or ocean floor. With one of the patients being a professional skimboarder, it is speculated that spinal cord injury is of definite concern as skimboarders develop and perform more extreme maneuvers [44].

Conclusion

Surfing is an exciting sport enjoyed in many coastal communities around the globe. Participants are prone to various conditions ranging from acute injuries to conditions borne from chronic environmental exposure. Lacerations, contusions, sprains, and fractures are the common types of acute traumatic injury. Injury from the rider’s own surfboard is the prevailing mechanism of injury. Injuries occur often in competition, especially at the professional level. Surfer’s myelopathy is a newly described condition, typically in novice surfers that can lead to paraparesis or paraplegia. Interaction with marine animals may lead to injury through envenomation. Exposure to jellyfish and other nematocyst-containing larvae can cause a reaction known as seabather’s eruption. Stingrays and coral reefs present further hazards to the surfboard rider. Infection of wounds is often seen and should be treated with fluoroquinolones or third-generation cephalosporins to cover *Vibrio* species, along with *Staphylococcus* and *Streptococcus*. Otologic sequelae of surfing include auditory exostoses, ruptured tympanic membrane, and otitis externa. Skimboarding is a relatively new and growing sport, with common injuries including contusions, abrasions, and fractures, usually occurring at the lower extremities.

References

1. Nathanson A, Haynes P, Galanis D. Surfing injuries. Am J Emerg Med. 2002;20:155–60 (Recent addition to literature and comprehensive review).
2. Mendez-Villaneuva A, Bishop D. Physiological aspects of surfboard riding performance. Sports Med. 2005;35(1):55–70 (One of the only studies assessing fitness level of surfer’s).
3. Lowdon BJ, Pateman NA, Pitman AJ. Surfboard-riding injuries. Med J Aust. 1983;2:613–6.
4. Nathanson A, Bird S, Dao L, Tam-Sing K. Competitive surfing injuries. A prospective study of surfing-related injuries among contest surfers. Am J Sports Med. 2007;35(1):113–7.
5. Sunshine S. Surfing injuries. Curr Sports Med Rep. 2003;2:136–41 (Papers of particular importance or recent additions to the literature base).
6. Kim JW, McDonald R, Rubsamen PE, Luttrull JK, Drouilhet JH, Frambach DA. Surfing related ocular injuries. Retina. 1988;18:424–9.
7. Lawless M, Porter W, Pountney R, Simpson M. Surfboard-related ocular injuries. Aust NZ J Ophthalmol. 1986;14:55–7.

8. Thompson TP, Pearce J, Chang G, Madamba J. Surfer's myelopathy. Spine. 2004;29(16):353–6 (Recent case series describing new disorder of surfer's).
9. Shuster A, Franchetto A. Surfer's myelopathy-an unusual cause of acute spinal cord ischemia: a case report and review of the literature. Emerg Radiol. 2011;18(1):57–60.
10. Karabegovic A, Strachan-Jackman S, Carr D. Surfer's myelopathy: case report and review. CJEM. 2011;12(5):357–60.
11. Fessa C, Lee B. An Australian case of Surfer's myelopathy. Clin J Sport Med. 2012;22:281–3.
12. Takakura T, Yokoyama O, Sakuma F, Itoh R, Romero R. Complete paraplegia resulting from Surfer's myelopathy. Am J Phys Med Rehabil. 2013;92:833–7.
13. Aoki M, Moriizumi S, Toki M, Murakami T, Ishiai S. Rehabilitation and long-term course of nontraumatic myelopathy associated with surfing. Am J Phys Med Rehabil. 2013;92:828–32.
14. Leiske J, Cameron B, Drinkwine B, Goertzke S, Alemi L, Needham K, Ventura J, Ho V, Barge D. Surfer's myelopathy-demonstrated by diffusion-weighted magnetic resonance imaging: a case reports and literature review. J Comput Assist Tomogr. 2011;35(4):492–4. doi:10.1097/RCT.0b013e31821e277b.
15. Dhaliwal P, Cenic A, Eesa M, Plessis S. An unusual case of myelopathy: Surfer's myelopathy. Can J Neurol Sci. 2011;38:354–6.
16. Lin Y, Fu J, Li S. Surfer's myelopathy. Q J Med. 2012;105:373–4.
17. Chung H, Sun S, Wang J, Lai P, Hwang C. Nontraumatic anterior spinal cord infarction in a novice surfer: a case report. J Neurol Sci. 2011;302:118–20.
18. Aviles-Hernandez I, Garcia-Zozaya I, DeVillasante J. Nontraumatic myelopathy associated with surfing. J Spinal Cord Med. 2007;30:288–93.
19. Nakamoto B, Siu A, Hashiba K, Sinclair B, Baker B, Gerber M, McMurtray A, Pearce A, Pearce J. Surfer's myelopathy: a radiologic study of 23 cases. AJNR Am J Neuroradiol. 2013;34:2393–8.
20. Robles LA. Cervical spine injuries in ocean bathers: wave-related accidents. Neurosurgery. 2006;58(5):920–3 (Recent addition to the medical literature).
21. McGoldrick J, Marx JA. Marine envenomations; part 1: vertebrates. J Emerg Med. 1991;9:497–502.
22. Hartwick R, Callanan V, Williamson J. Disarming the box jellyfish: nematocyst inhibition in chironex fleckeri. Med J Aust. 1980;1:15–20.
23. Burnett JW, Rubinstein H, Calton GJ. First aid for jellyfish envenomation. South Med J. 1983;76:870–2.
24. Exton DR, Fenner PJ, Williamson JA. Cold packs: effective topical analgesia in the treatment of painful stings by Physalia and other jellyfish. Med J Aust. 1989;151:625–6.
25. Thomas CS, Scott SA, Galanis DJ, Goto RS. Box jellyfish (Carybdea alata) in Waikiki: their influx cycle plus the analgesic effect of hot and cold packs on their stings to swimmers at the beach: a randomized, placebo-controlled, clinical trial. Hawaii Med J. 2001;60:100–7 (Controlled trial of differential effects of various modalities in pain relief).
26. Nomura JT, Sato RL, Ahern RM, Snow JL, Kuwaye TT, Yamamoto LG. A randomized paired comparison trial of cutaneous treatments for acute jellyfish (Carybdea alata) sting. Am J Emerg Med. 2002;20:624–6 (Controlled trial of differential effects of various modalities in pain relief).
27. Otten EJ, Blomkalns AL. Venomous animal injuries. In: Marx JA, editor. Rosen's emergency medicine: concepts and clinical practice. 5th ed. St. Louis: Mosby; 2002. p. 799.
28. Freudenthal AR, Joseph PR. Seabather's eruption. N Engl J Med. 1993;329:542–4.
29. Rossetto A, Dellatorre G, Silveira F, Junior V. Seabather's eruption: a clinical and epidemiological study of 38 cases in Santa Catarina State, Brazil. Rev Inst Med Trop Sao Paulo. 2009;51(3):169–75.
30. Kumar S, Hlady GW, Malecki JM. Risk factors for seabather's eruption: a prospective cohort study. Public Health Rep. 1997;112:59–62.
31. Burnett JW. Seabather's eruption. Cutis. 1992;50:98.
32. Auerbach PS. Marine envenomations. N Engl J Med. 1991;325:486–93 (Papers of particular importance or recent additions to the literature base).
33. Nichols AW. Nonorthopedic injuries in the aquatic athlete. Clin Sports Med. 1999;18:395–411.
34. Kroon DF, Lawson ML, Derkay CS, Hoffmann K, McCook J. Surfer's ear: external auditory exostoses are more prevalent in cold water surfers. Otolaryngol Head Neck Surg. 2002;126:499–504 (Recent addition to the medical literature).
35. Deleyiannis FWB, Cockcroft BD, Pinczower EF. Exostoses of the external auditory canal in Oregon surfers. Am J Otolaryngol. 1996;17:303–7.
36. Wong BJF, Cervantes W, Doyle KJ, Karamzadeh AM, Boys P, Brauel G. Prevalence of external auditory canal exostoses in surfers. Arch Otolaryngol. 1999;125:969–72.
37. Sander R. Otitis externa: a practical guide to treatment and prevention. Am Fam Physician. 2001;63:927–36, 941–2.
38. Richmond DR, Yelverton JT, Fletcher ER. Physical correlates of eardrum rupture. Ann Otol Rhinol Laryngol. 1989;98(140):35–41.
39. Kerr AG. The effects of blast on the ear. J Larygol Otol. 1980;94:107–10.
40. Donnelly L, Betts J, Fricke B. Skimboarder's Toe. Findings on high-field MRI. AJR Am J Roentgenol. 2005;184:1481–5.
41. Sciarretta K, McKenna M, Riccio A. Orthopaedic injuries associated with skimboarding. Am J Sports Med. 2009;37:7.
42. Williams M, Poulter R, Fern E. Skimboarding: a new danger in the surf? Emerg Med J. 2006;23:137.
43. Merriman D, Carmichael K, Battle S. Skimboard injuries. J Trauma. 2008;65:487–90.
44. Collier T, Jones M, Murray H. Skimboarding: a new cause of water sport spinal cord injury. Spinal Cord. 2010;48:349–51.

Windsurfing Medicine

21

Francesco Feletti

21.1 Windsurfing

21.1.1 Origins

A sailboard is defined as a surfboard with a free sail system, a swivel-mounted mast set on a free-rotating universal joint [1]. Although modern windsurfing has its origins in the 1950s [2], it is unclear as to whether the sport had a single inventor or if various experiences led to similar results. In 1948, a 20-year-old American, Newman Darby, began developing the idea of a rudderless, keelless sailboard with a rig mounted on a universal joint allowing sailors to steer by orienting the sail manually and shifting their weight. Darby began selling his "sailboard kit" in 1964. The British inventor and engineer, Peter Chilvers, is also credited with the creation of an early version of a sailboard in 1958 on Hayling Island on the south coast of England [3]. Also in 1964, the aircraft engineer Jim Drake and the businessman Hoyle Schweitzer began experimenting with a surfboard made from foam and teak with a sail mounted on a rotational system allowing the angle of attack of the sail to the board to be varied and a rope attached to the boom to pull the sail out of the water. The system allowed the sailboarder to control both sail power and craft direction and was finally patented by Drake and Schweitzer with the name "wind-propelled apparatus" granted by the United States Patent and Trademark Office (USPTO) in 1970 [4]. In 1973, they registered the term "windsurfer" as a trademark at the USPTO and launched the craft as a one-design class. Thanks to Schweitzer's untiring promotion, the sport enjoyed a rapid rise in popularity throughout the 1970s leading to its inclusion in the Olympic Games from 1984 onwards in the form of a course racing event.

21.1.2 Disciplines

Today, *World Sailing* (formerly known as ISAF: International Sailing Federation) [5] recognizes 13 board classes consisting of three kiteboarding classes and ten windsurfing classes including the *International RS:X Class* [6] – the male and female windsurfing Olympic Class in the 2016 Olympic Games in Rio de Janeiro. The Professional Windsurfers Association (PWA) [7] recognizes events in the following disciplines: race (*Slalom 42*), *Super X*, freestyle, wave performance and indoor. Race and slalom events are similar to sailing regattas that are

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Fig. 21.1 Wave jumping. In this discipline, the peaks of unbroken waves are used like a ramp allowing athletes to perform aerial stunts. Wave sailing is the most extreme discipline in windsurfing, which is practiced in strong wind conditions and large waves (Photo: Claudio Marosa)

held over different courses depending on the specific class. In slalom, windsurfers compete along a slalom course in strong wind conditions, while Super X also is performed along a short slalom course but involves tricks. In *speed surfing*, the aim is to complete a 500-m course in the shortest possible time, and speeds over 50 knots have been registered [8, 9]. Freestyle and wave sailing events are judged competitions in which various tricks are performed. In wave events, performance jumps, wave riding and transitions are performed, usually on large waves and in strong wind conditions (Fig. 21.1). Indoor windsurfing, slalom, freestyle and jumping competitions are also held in winter, especially in Europe [10].

21.1.3 Equipment

The equipment used in windsurfing varies considerably depending on a number of factors including weather conditions and the particular discipline practiced. In *Formula Windsurfing*, the highest performance course racing class, equipment is used with the largest surface area since events involve sailing upwind and are even held in light winds. Sail sizes can reach 12.5 m^2 and boards may have widths of up to 1 m with fins measuring up to 70 cm in length. Wave boards, at the other extreme, are small, light and highly maneuverable: the volume in liters is generally comparable to the weight of the sailor in kilograms, while the sail area is commonly in the range of 4–6 m^2.

In slalom events, equipment is designed to achieve top speed because there are no path distances upwind, and a minimum wind speed of 11 knots (20 km/h) is required for races [11]. Freestyle equipment is similar to wave equipment but considerably larger and specifically shaped to perform acrobatic tricks on flat water, including jumps, rotations, slides, flips and loops. The discipline known as *free riding* is a recreational style in which athletes use various sizes of boards dependent on weather conditions and their own preferences. Fairly large boards (around 130 l) and well-controllable sails (approximately 6–7 m^2) are preferred [12]. Speed events involve the use of special, extremely narrow boards launched at speeds of over 45 knots on flat water with the aim of setting new speed records.

21.1.4 Sailing Technique

Windsurfers can sail both in displacement mode, cutting through the water like a sailboat, or preferably in planing mode, skipping over the water's

Fig. 21.2 In wave riding, the windsurfer rides the face of a wave performing narrow-linked turns such as *bottom turns*, *cutbacks* and *top turns* (Photo: Claudio Marosa)

surface when the wind speed exceeds 10 knots (about 19 km/h). When planing, the windsurfers maintain the sail rig in a back position on the board, their feet are in the foot straps, and they are typically attached to the mast by means of a harness to counterbalance wind pressure on the sail. As wind strength increases, equipment decreases in size; boards with lower volumes and shorter in length and width and sails with a reduced surface area are preferred. The directional control of the windsurf is mainly achieved by the rider shifting his/her weight and adjusting the position of the rig with respect to the board. As in sailing, the main windsurfing maneuvers are tack and jibe with the exception of wave riding where heel side turns while planing (*cutbacks*) are the only maneuvers used (Fig. 21.2).

21.2 Injuries and Illnesses

Although windsurfing enjoys the reputation of being a fairly safe activity, a number of injuries may occur including acute and overuse injuries. When practicing windsurfing, the management of common injuries such as wounds requires specific precautions. Infectious diseases are also reported and occur due to the fact that windsurfing is often tolerated in areas where bathing is not considered to be safe because of water pollution.

21.3 Acute Injuries

21.3.1 Injury Rate

Most of the data on injuries is from retrospective studies based on questionnaires or from medical records collected for other purposes. This makes it prone to different limitations (including recall bias or underestimation of minor injuries) and potentially leads to imprecise epidemiological evaluations [13]. Taking into account these considerations, the available data as a whole nevertheless allows us to draw a general risk profile of the sport (Table 21.1).

According to the relevant literature, acute injuries range between 69 and 78 % of all windsurfing injuries [13, 21]. With respect to injury distribution, lower limbs are the part of the body most commonly affected (Table 21.2). Most injuries are lacerations or puncture wounds due to contact with equipment and the sea floor and sprains or fractures due to the foot straps.

In the series by Nathanson and Reinert [13], out of 339 acute injuries, the foot was the most common site of acute injury (17.7 %; $n=65$), followed by the knee (9.4 %; $n=32$), and the ankle (8.6 %; $n=29$). Foot injuries were mainly lacerations (48 %; $n=31$), while more than half (57 %; $n=35$) of knee and ankle injuries considered together were sprains. The upper limbs were the

Table 21.1 Windsurfing injury rates according to different studies

Study	Population	Total number of participants	Type of data	Injury rate
McCormick and Davis (1988) [14]	Enthusiasts including the "hurricane sailors" of Galveston Bay, Texas, in the Gulf of Mexico	73	Hospital medical records and questionnaire interviews	0.22/1000 windsurfing hours
Mettler and Biener (1991) [15]	Members of the Swiss Windsurfing Federation	189	Medical history	0.02 injuries/athlete/year
Salvi et al. (1997) [16]	National and international competition windsurfers taking part in the 1993 Italian Championship	123	Medical history	0.003 injuries/athlete/year 0.22/1000 windsurfing hours
Nathanson and Reinert (1999) [13]	Predominantly amateurs (99.3 %), practicing in the United States and the Dominican Republic, and recruited via the Internet	294	Specific questionnaire	0.36/1000 windsurfing hours
Prymka et al. (1999) [17]	Competitors in the German Windsurfing Cup 1995	44	Specific questionnaire	2.04/person/year (extrapolated)
Petersen et al. (2003) [18]	Recreational (72 %), competitors (20 %), and beginner (8 %) German windsurfers in the 2000 season	327	Specific questionnaire	1.92/participant/year (extrapolated)
Dyson et al. (2006) [19]	Race board national/international competitors (33.6 %), wave/slalom national/international competitors (40.2 %), and recreational windsurfers (26.2 %) in the 1999/2000 seasons	107	Specific questionnaire	1.5/person/year
Kristen et al. (2007) [20]	Participants in the Windsurf Freestyle World Cup/Euro-Cup during the period 1997–2007, Neusiedl, Austria	27 (average)	Sports medical records	0.69/athlete/year (extrapolated)

Table 21.2 Anatomical distribution of injuries according to different studies

Authors	Total number of injuries	Head/neck (%)	Trunk (%)	Upper limbs (%)	Lower limbs (%)
Nathanson and Reinert (1999) [13]	339	17.8	16	18.5	44.6
Prymka et al. (1999) [17]	25	16	8	20	56
Kristen et al. (2007) [20]	188	26	19	6	38
Gosheger et al. (2001) [22]	260	17	15	9	59
Hopkins and Hooker (2002) [23]	222	25	9	8	48

second most affected area of the body (18.5 %; $n=62$) with ligamentous injuries and sprains (55 %; $n=34$) and shoulder dislocations (15 %; $n=9$). Head injuries mainly consisted of contusions (4.7 %; $n=16$), while injuries to the trunk were mostly chest wall contusions and rib fractures (8.2 %; $n=28$) and back strains or intervertebral disk injuries (4.7 %; $n=16$).

A similar injury pattern was found in competitors and elite windsurfers. In a study on 49 professional World Cup windsurfers, Gosheger et al. [22] found ankle strains to be the most common injuries (22 %; $n=57$). Knee injuries were also frequent (11.5 %; $n=30$). In the study by Kristen et al. [20] examining the Windsurf Freestyle World Cup/Euro-Cup regattas on Lake Neusiedl in Austria between 1997 and 2007, the most common injuries were as follows: sprains and ligament tears to the ankle and foot (18 %; $n=34$); acute back pain (17 %; $n=32$); head contusions

(12.8 %; $n=24$); cuts to the feet (11 %; $n=21$); and knee injuries (9 %; $n=17$). In their study on elite women windsurfers participating in the 2008 PWA World Cup in Fuerteventura in the Canary Islands, Penichet-Tomás et al. [24] found that knees and legs were the most common regions to be affected by injuries in slalom and freestyle respectively. In the series by Dyson et al. [19], muscle/tendon strains accounted for 45 % of new injuries, and acute soft tissue injuries were equally distributed in the upper ($n=129$) and lower body ($n=133$). Especially in the upper body, most of the injuries affected the shoulder, the upper arm, and the elbow complex (41 %), while 60 % of lower body soft tissue injuries were most frequently related to the knee or the lower leg, the ankle and foot. Finally, in the same study, serious bruising, cuts and abrasions (mainly involving the head and face, the leg and foot regions) were more common especially among wave and slalom.

Although most injuries sustained during windsurfing are minor (sprains, muscle strains, bruises and cuts [12, 13, 18–20]), more serious injuries may occur when windsurfing is practiced in extreme wind and wave conditions or when simple safety rules and procedures are not followed [25]. Kalogeromitros et al. [25] monitored all serious windsurfing incidents in the Aegean Sea during 1999 and reported 22 windsurfing injuries requiring hospitalization at a tertiary level center. These included two cases of drowning, three concussions (one serious enough to require mechanical ventilatory support for 24 h), and a young windsurfer who suffered a C2 fracture resulting in tetraplegia associated with tracheal obstruction requiring emergency tracheotomy.

21.3.2 Causes of Acute Injuries

Collision with equipment when overpowered by wind and waves is the most common cause of trauma [18]. This is the cause in 65–75 % of all injuries [13, 15], the majority of which are caused by the boom, mast and board [13, 23]. In the series by Nathanson and Reinert [13], more than one third of lacerations to the lower limbs were caused by the surfer striking the fin of the board while attempting to waterstart with long narrow "blade" fins causing significantly more injuries (68.5 %; $n=13$) than swept-back wave-type fins (31.5 %; $n=6$).

According to Fehske et al. [12], 22.3 % of injury events had an external cause such as collisions with kitesurfers or other watercraft. These were not considered as common causes of injury in other studies [12, 13]. According to Nathanson and Reinert [13], the impact with water and contact with the seafloor and marine animals were other important causes of injuries accounting for 12.1 % of the total when taken together. Reports of shark attacks on windsurfers are extremely rare [26]. A greater danger in tropical waters is posed by flying fish which can cause cuts, while collisions with marine turtles can be avoided by paying attention to the fairway [20].

Most injury events occur after 2 h of exercise. This may be caused by fatigue interfering with the proper execution of maneuvers [19]. Broken equipment was reported as a cause of injury in just 3 % ($n=10$) of cases (Peterson et al. [18]).

Drowning is uncommon, as is hypothermia; in extreme cases, the latter can be fatal, and every possible measure should be adopted to prevent its occurrence [13, 25, 26].

21.3.3 Injury Dynamics

According to Nathanson and Reinert [13], uncontrolled falls represent the most common injury dynamic resulting in more than one third of injuries.

Low-speed falls mainly lead to lower limb injuries ascribed to the pattern of "foot strap injuries"(Fig. 21.3), while high-speed falls may cause shoulder and head injuries consistent with the mechanism of "catapulting"[13]. The latter occurs when sailors are unable to detach the harness quickly enough causing them to be launched into the air and often land on the mast or the boom. Anterior shoulder dislocations are usually caused by the boardsailor hanging onto the boom while falling. Falls can also lead to head injuries ranging from minor results such as hearing

Fig. 21.3 A windsurfer photographed just before a fall caused by miscalculation of the ratio between sailing speed and wave size. The sail is clearly deflated with the low wind pressure giving no potential for recovery. The breaking wave may complicate the fall resulting in dynamic a high-risk for foot strap injuries (Photo: Claudio Marosa)

Fig. 21.4 One-handed jump (Photo: Claudio Marosa)

problems and tinnitus to severe concussion with loss of consciousness [25]. In the study by Nathanson and Reinert [13], jumping was the maneuver that most often led to injuries (21 %; $n = 71$), while launching, jibing, and waterstarting caused 9.4, 7, and 5.9 % of injuries respectively (Fig. 21.4)

Since even the most extreme athletes spend less than 5 % of their windsurfing time jumping, this maneuver contributes to a disproportionately high number of injuries. Jumping, looping, and catapult falls also tend to cause injuries requiring medical treatment [13]. In addition, jumps involving rotations of the board and the athlete on both horizontal and vertical planes such as *forward* and *backward* looping are the most dangerous maneuvers (Fig. 21.5) [18]. While the consequences of the collisions with kitesurfers or other watercraft are generally absent or minimal, given that windsurfers can reach speeds of 30–60 km/h, potential outcomes include major injuries such as blunt trauma from the board top,

Fig. 21.5 Landing from a *push loop* (Photo: Claudio Marosa)

Fig. 21.6 A dangerous situation: a fallen windsurfer in large breakers (Photo: Claudio Marosa)

craniocerebral trauma and cuts from the fin [20]. Collisions are especially common in the most popular windsurfing spots near cities, often crowded with windsurfers, kiters, and sailors especially during weekends, and they are caused by lack of concentration, ignorance or disregard of the right of way, and high-risk maneuvers [20]. Meteorological conditions, particularly strong winds and large waves [14], may also lead to incidents (Fig. 21.6), especially when weather conditions are unexpected or underestimated [18, 19].

21.4 Acute Injuries Specific to Windsurfing

21.4.1 Foot Strap Injuries

The category of injuries referred to as "foot strap injuries" [22] is specific to windsurfing [16, 28] and represents the vast majority (75 %) of lower limb fractures and ligament injuries [13] involving the ankle, knee or foot. They occur during unexpected falls or a bad landing after a jump and are caused by the dispropor-

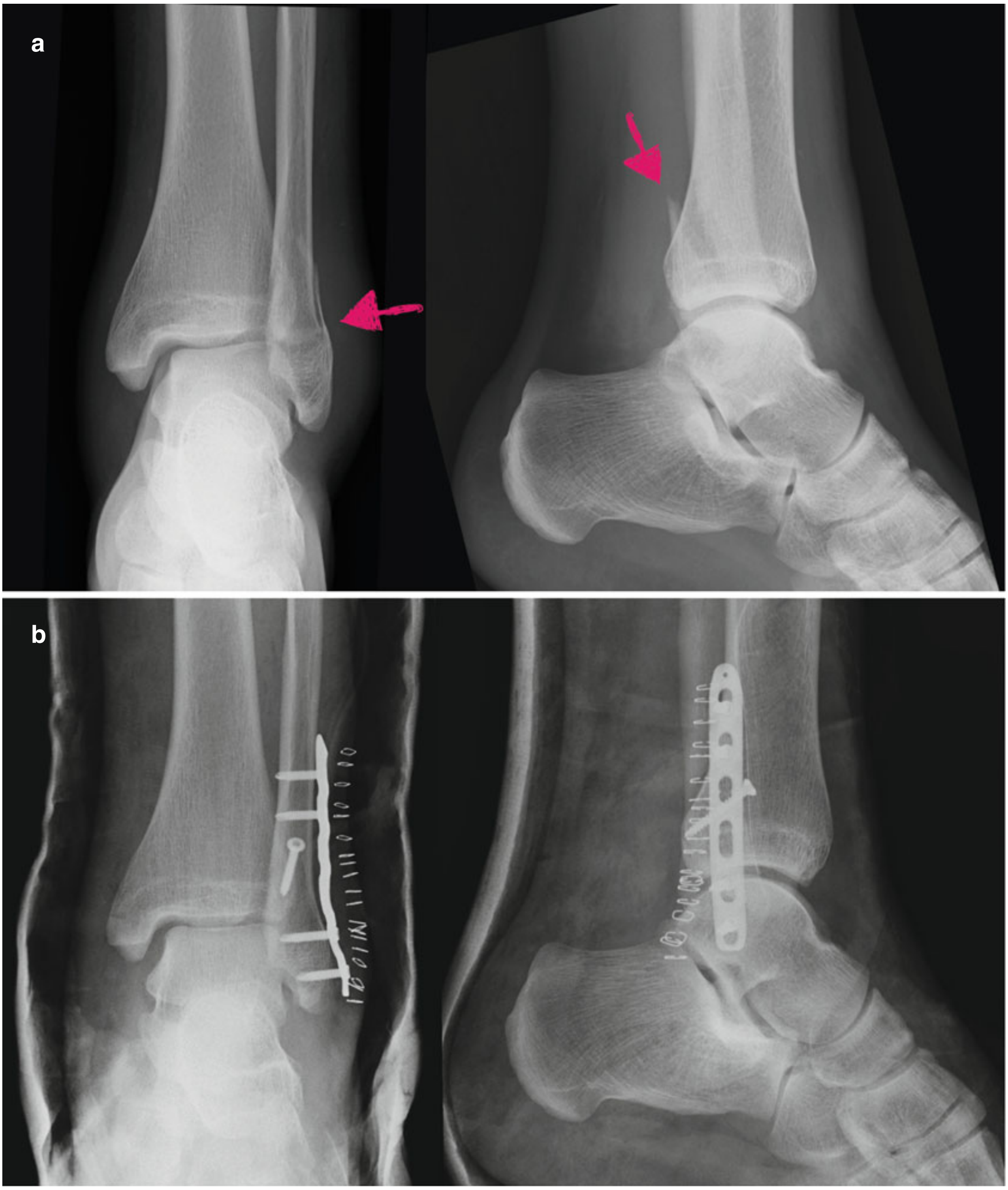

Fig. 21.7 Foot strap injury: distal fracture of the fibula, diagnosis, and treatment. Radiographs: anteroposterior (**a**) and laterolateral (**b**) projections. showing fracture (*indicated by an arrow*). Radiographs in the same projections, showing the reduction achieved using a plate, metal screws and plaster splint [1]

tionate rotational forces exerted on the lower limbs by the long lever arm of the board when the foot is wedged in the foot strap. This is a mechanism whereby the body twists at the knee on the fixed foreleg possibly causing fractures of the femoral shaft [25], the head of the fibula (Fig. 21.7) and the tibial plateau, as well as knee injuries including dislocations, lesions of the capsule, and tears to the meniscus and collateral and cruciate ligaments [28]. Foot and ankle injuries may also occur when the foot inserted in the foot strap is acutely pronated due to a bad landing or a fall. These include Lisfranc injuries; unusual in other sports, but potentially frequent in windsurfing [36].

The term *Lisfranc injury* refers to a wide spectrum of injuries including lesions to the bases of the metatarsals, the four distal tarsal bones and the Lisfranc ligament. The tarsometatarsal joint complex (also referred to as the Lisfranc joint) is architecturally shaped like a “Roman arch” with the base of the second metatarsal acting as its keystone. It is located proximally with respect to the other metatarsal bases, tightly recessed between the first and third cuneiforms in a mortise configuration. The Lisfranc ligament is a strong oblique ligament arising from the plantar-lateral surface of the medial cuneiform to insert on to the plantar medial aspect of the second metatarsal. The traumatic mechanism of these injuries usually involves excessive plantar flexion and abduction of the forefoot often associated with concurrent rotational, compressive, and translative forces [29].

A high level of vigilance is required when evaluating windsurfers who suffer from injuries stemming from this dynamic since delayed diagnosis may lead to post-traumatic arthritis. On examination, anterior foot pain may be associated with ecchymosis or edema of variable entity. In Lisfranc ligament injuries, pain is elicited by moving the first and second metatarsals in opposite directions or by passive abduction and pronation of the forefoot while holding the hindfoot in a fixed position. Plain radiography should be completed with an anterior-posterior weightbearing view and may allow the physician to detect the following signs: misalignment of the medial border of the second metatarsal with the medial margin of the middle cuneiform; diastasis between the first cuneiform and the second metatarsal base; and a small bony fragment between the base of the first and second metatarsal (*fleck sign*). CT and MRI are more reliable. MRI in particular may show ligament edema as an increased signal on T2-weighted sequences in the case of a strain or ligament discontinuity in the case of a tear, or fractures of the metatarsal bases and tarsal bones, while bone marrow edema within the inferior aspect of the middle cuneiform should be considered a secondary sign of ligament injury. CT is more sensitive to bone injuries allowing a better visualization of these fractures and aiding preoperative planning [28, 31].

Although the best approach to Lisfranc injuries is still debated, stage I (according to Nunley and Vertullo [32], Fig. 21.8) can be non-surgically managed by a non-weightbearing cast for 6–10 weeks with the majority of patients returning to their pre-injury sport activities. With regard to stage II and III injuries, most authors agree that the best treatment strategy involves prompt surgical intervention with anatomic reduction and fixation [32–35]. Despite this, Mitani et al. [36] reported the case of a 40-year-old professional female windsurfer who sustained a Lisfranc injury with a diastasis of more than 3 mm that was treated conservatively. Undeterred by the recommendation for surgical treatment, she was adamant in her preference for non-surgical management. Given that she was close to the late stages of her professional career, a long rest and rehabilitation period required by a surgical approach would have hastened her retirement. The conservative approach was possible because her specialty was racing which is much less demanding compared to wave riding and freestyle in terms of forefoot stresses in the foot straps, A special cork insole mounted inside a marine boot was adopted to support the longitudinal and lateral arch of the foot during windsurfing even when in the strap.

To prevent foot strap injuries, the foot straps should permit the feet to be removed quickly and easily in the event of a fall or a bad landing from a jump. It is therefore recommended that the strap is sufficiently tightened to prevent the foot from going further than the metatarsophalangeal joint. Actually, if the foot straps are too loose, the feet tend to slip (or be placed) too far under the strap making them difficult to remove promptly in the event of a fall or poorly executed maneuver [36]. Alternatively, Witt et al. [28] propose that foot straps should be fitted with an appropriate quick release system.

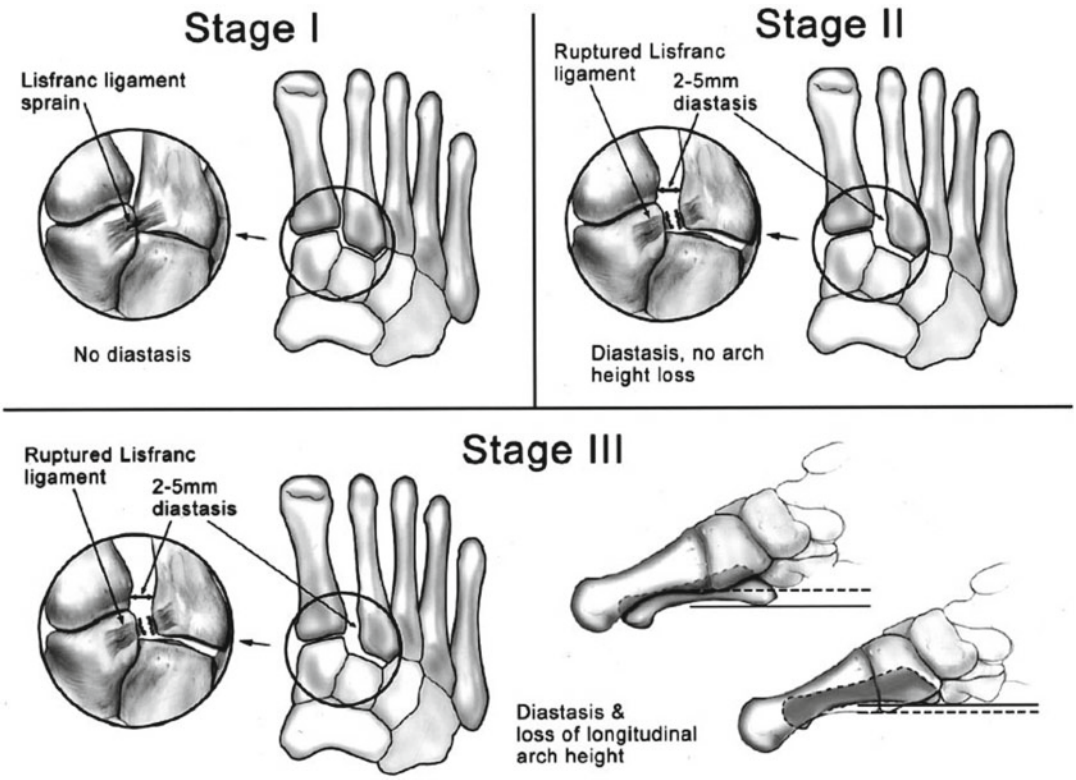

Fig. 21.8 Nunley and Vertullo's classification of Lisfranc injuries. *Stage I* corresponds to ligament sprain with no diastasis between the second metatarsal and the first cuneiform on anteroposterior weightbearing radiograph; *Stage II* relates to diastasis of 2–5 mm without associated loss of longitudinal arch height on the lateral weightbearing radiograph; *Stage III* involves loss of arch height associated with abnormal diastasis (Reprinted with permission from: Nunley and Vertullo [32])

21.4.2 Shoulder Injuries

Anterior shoulder dislocations have long been reported in windsurfing injuries [37] accounting for 15 % of upper limb injuries in the study by Nathanson et al. [13] and 23 % ($n=5$) of all severe injuries affecting inexperienced windsurfers reported by Kalogeromitros et al., [25]. While maintaining a pull on the sail, windsurfers keep their arms almost parallel. A fall in this position while hanging onto the boom may lead to anterior shoulder dislocations as a consequence of abrupt abduction and external rotation of the arm [13, 25] (Fig. 21.9).

On examination, the dislocated shoulder appears squared having lost its natural curve. The typical antalgic position consists of the patient keeping the elbow flexed supporting the forearm with the contralateral hand, and patients are unable to reach the opposite shoulder with the hand of the injured arm. Reduction at the scene may be safely and effectively attempted by non-medical personnel with specific training in the technique [38]. Any attempt at reduction should be avoided in the case of a posterior dislocation or when an associated fracture of the arm or clavicle is suspected. For this reason, before starting any technique, it is essential to rule out any collar bone fractures by gently pushing on the patient's clavicle as well as assessing the radial pulse, grip strength of the hand and range of motion of the arm on the affected side. It is also crucial to exclude any lack of tactile sensitivity on the external side of the shoulder which is a sign of axillary nerve lesion. The same parameters should be reassessed following reduction in order

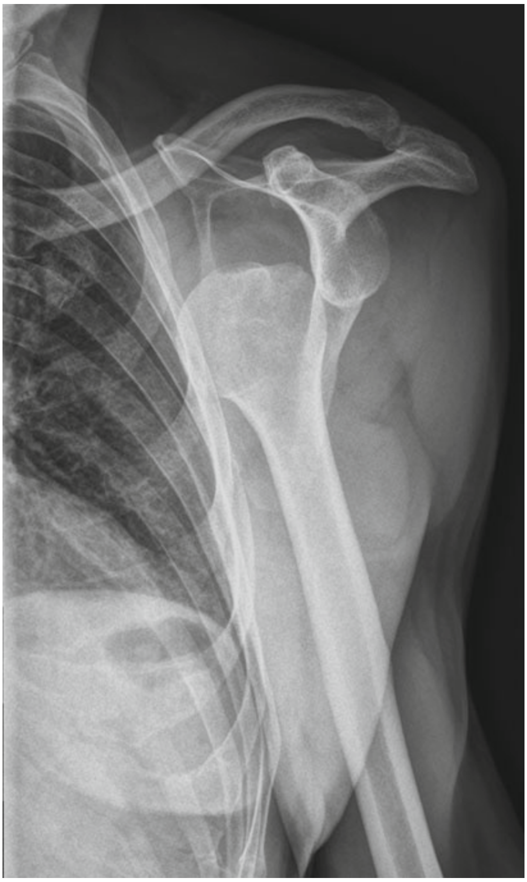

Fig. 21.9 Shoulder dislocation in a long-experienced windsurfer which occurred by the dynamic described in text

to exclude any changes [2]. There are also several self-reduction techniques such as “knee-wrap reduction” in which injured persons assume a seated position, clasp both hands around their bent knees and lean back slowly achieving shoulder reduction spontaneously [39]. If reduction is not attempted or is unsuccessful, or in the case of circulation, sensation or movement abnormalities, the patient should be evacuated to the nearest emergency department with the arm immobilized in the adducted position.

A case of injury to the axillary artery while windsurfing with subsequent thrombosis was reported as a consequence of direct trauma due to repeated falls in water on the abducted arm [40]. Although anecdotal, the possibility of this traumatic injury must be taken into account. In such cases, an aggressive treatment approach is indicated and justified since any delay may lead to permanent tissue changes leaving the affected limb unable to sustain the strenuous activity the sport requires.

Sibilia [41] reported the case of an acute suprascapular neuropathy affecting a 21-year-old experienced, male windsurfer who reported a sharp, dagger-like pain in his shoulder as he was lifting his sail out of the water while performing windsurfing tricks. He immediately stopped windsurfing but continued to suffer from diffuse shoulder pain and aching several days after the event. A subsequent examination revealed shoulder muscle atrophy and weakness of shoulder abduction and external rotation while electromyography (EMG) was consistent with a suprascapular neuropathy at the suprascapular notch. Conservative treatment with rest and physiotherapy led to his recovery and return to windsurfing 6 months later without any limitations. The acute mechanism of windsurfing suprascapular nerve injuries involves a stretching of the nerve when it passes through the suprascapular notch during an acute forceful rotation of the scapula. Suprascapular neuropathy may also be the consequence of a scapular fracture or acute blunt trauma to the nerve [42]. This nerve may also be chronically compressed by a ligament, ganglion or callus after a fracture.

21.4.3 Head Injuries

Head injuries are mainly caused by impact with the mast or boom [13] especially as a consequence of falls [25] or poor landings from more spectacular jumps such as *loops* or *table tops* [22]. Head trauma is more common in wave and slalom disciplines [19] and may result in concussion, eardrum perforation, tooth avulsions and facial fractures [13, 18, 19, 25]. Head injury prevention measures by beginners include wearing a helmet to cushion possible collision with the sailing rig, but experienced windsurfers should also use a helmet especially in high wind conditions and in crowded areas during wave and slalom activities or when performing aerial maneuvers

[19, 43]. While earplugs or neoprene headbands may provide protection against eardrum injuries, experienced windsurfers are unlikely to adopt such measures since they limit sensitivity to detecting slight changes in wind speed and direction necessary for optimal windsurfing performance. Sensible precautions also include the use of a personal flotation device, especially when the potential outcomes of head injuries including the risk of drowning are considered [25].

21.4.4 Chest Injuries

In windsurfing, rib fractures represent the most common thoracic injury and the most common type of fracture [18], and these may be complicated by pneumothorax [25]. The proper technique required to maintain the pull on the sail against wind resistance involves a sustained isometric contraction of the pectoralis major, deltoid and scapular stabilizers. As a consequence, a sudden significant increase in wind strength may add a forceful overload to already contracted muscles potentially leading to muscle injuries [44]. A case of pectoralis major rupture with this dynamic was described by Dunkelman et al. [45]. While rupture of the pectoralis major is relatively uncommon, it is always complete and occurs at or near the insertion of the tendon on the humerus. Clinically, it manifests with immediate pain at the medial aspect of the upper arm and swelling and ecchymosis in the pectoralis region associated with loss of strength in adduction movements. Another sign is loss or thinning of the anterior axillary fold accentuated by abducting the arm or with resisted adduction [46]. The role of plain radiographs is limited to differential diagnosis with bony shoulder injuries and to the rare case of a bony avulsion. Sonography is an effective tool in confirming clinical suspicions and avoiding delay in surgery. MRI with an extended field of view running from the quadrilateral space to the deltoid tuberosity along with coronal oblique cuts can more accurately determine the amount of muscle retraction and may be useful for surgical planning. Treatment is based on reinsertion of the tendon in the humerus as well as an adequate period of rest associated with a rehabilitation program that includes exercises to recover the complete range of motion and to increase endurance and strength.

21.4.5 Spinal Injuries

Spinal burst fractures, wedge compression fractures, fracture dislocations, herniation of the intervertebral disks and spinal cord injuries are all possible consequence of a fall or of being struck by equipment when overpowered by wind [42, 44]. Actually, Patel et al. [47] reported the cases of two windsurfers aged 30 and 19 who suffered thoracic spinal cord injury after windsurfing in rough weather and strong wind conditions. Both experienced intense pain in the mid-thoracic region. Upon examination, the older patient showed a sensory level to pain and temperature at T7 on the right, increased tone with ankle clonus in the lower left limb, and absence of the left abdominal reflexes. The younger patient showed pyramidal weakness in the left leg with exaggerated knee jerks and bilateral extensor plantar responses, decreased lower abdominal reflexes, and a sensory deficit on the left at T10 level. The imaging of the thoracic spine showed only long-standing degenerative changes in both cases. Although pathogenesis of these injuries was unclear, it was attributed to impairment of arterial flow in a radicular vessel caused by exaggerated strain on the spine in forced hyperlordotic posture while windsurfing using a harness in association with previous degenerative changes of the spine. Both athletes made a full recovery within a few months.

21.5 Overuse Injuries

The true burden of overuse injuries could be substantially underestimated in the available studies mainly due to the methodological challenges involved in recording data [48]. Despite the difficulties in properly quantifying overuse injuries in windsurfing, it is possible to trace an outline by type and anatomical distribution. Low back pain is widely reported as the most common chronic

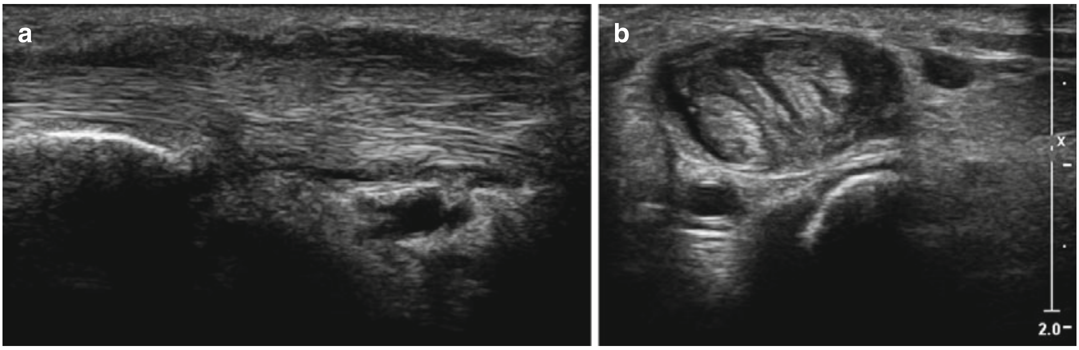

Fig. 21.10 De Quervain's syndrome. Ultrasound scans in the longitudinal (a) and axial (b) planes.

symptom [12, 13, 16, 19] followed by tendinitis and enthesitis. According to Salvi et al. [16], tendinitis and enthesitis-type injuries were mainly represented by epicondylitis (36 %), patellar tendinitis (22 %), and Achilles tendinitis (15 %), but tendinitis of the shoulder, De Quervain's syndrome, adductor tendinitis, peroneal tendinitis, and foot extensor tendinitis have also been reported [13, 16, 19, 20] (Fig. 21.10).

In the series by Fehske et al. [12], many stress-related symptoms were reported to the soft tissues in the forearms and the knee. Dyson et al. [19] reported recurrent and ongoing injuries as being much more common in the disciplines of wave and slalom. These injuries are not only a consequence of excessive practice, but also of improper technique [25], lack of specific training, or insufficient warm-up and stretching [16]. Muscle strengthening and optimal sailing technique with correct posture on the board, along with an adequate warm-up before each session, are the most effective means of minimizing or preventing overuse injuries.

21.5.1 Lower Back

Lower back pain is a common chronic condition among windsurfers, and both muscular tension and repetitive trauma contribute to its pathogenesis. In beginners, it is mainly caused by repetitive uphauling using poor technique. It could therefore be prevented by learning the appropriate technique to uphaul the rig which is bending the knees and keeping the back straight so that the weight of the body does most of the work. In advanced windsurfers, lower back pain may be due to a number of causes including poor harness technique, repetitive landing from high jumps, or holding sailing positions for a significant period of time particularly when sailing close-hauled or in light winds [20, 49]. Locke and Allen [49] examined seven elite boardsailors complaining of low back pain without radiation to the lower leg. When sailing positions were held for a long time, nothing but limited flexibility in some subjects was found on examination, while CT findings of disk protrusions, bulges, and pars interarticularis defects exceeded those in the normal population.

21.5.2 Upper Limbs

Chronic insertional tendinopathies, tenovaginitis, and compressive neuropathies due to the sustained and repetitive contraction of the upper limb musculature required to hold the boom are common in beginners and expert boardsailors alike [20]. Epicondylitis radialis and ulnaris are common conditions and should be differentiated from the symptoms of a radicular irritation of segments C6-C7 and C7-Th1. Different types of exertional compression of peripheral nerves have also been reported including carpal tunnel syndrome [19], posterior interosseus nerve (PIN) syndrome [50], and lateral antebrachial cutaneous (LAC) nerve compressive neuropathy [51]. In particular, PIN syndrome was reported by Ciniglio et al. [50] in 23 windsurfers suffering

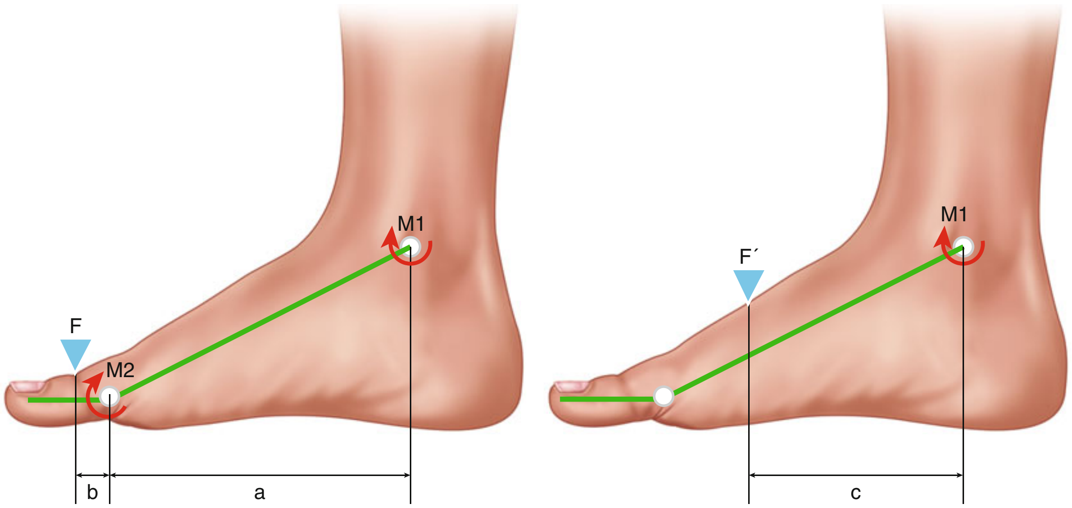

Fig. 21.11 Forces exerted on the foot by the foot straps; explanation in the text (Figure adapted from Hetsroni et al. [53])

from exertional upper limb paresthesia and weakness of the wrist extensor muscles, in some cases associated with pain in the anterior aspect of the forearm, on the extensor surface of the wrist, or close to the lateral epicondyle. The symptoms were recurrent during windsurfing sessions forcing athletes to interrupt their activity, and eased after maintaining the elbow and wrist flexed for a few minutes with the forearm supine and supported by the contralateral hand. All athletes were treated with a 2-week period of rest, massage, ultrasound and physical therapy. Five patients with persistent symptoms received further treatment which involved maintaining the elbow in flexion at 90° in a cast for 10 days followed by rehabilitative exercises. Symptoms recurred on resuming windsurfing in just one of these athletes. In this case, surgical exploration revealed a swollen PIN associated with fibrosis of the arcade of Frohse in the area of contact with the nerve. All were instructed to maintain the forearm in supination while holding the boom.

Many windsurfers tend to grip the boom with both hands or at least the leading hand in pronation. Using EMG analysis on a windsurfing simulator, Campillo et al. found that holding the boom with both hands in supination and using a wishbone with smaller diameter (28 mm rather than 30 mm) reduces flexor muscle activity in the fingers and prevents stress of the forearm muscles and related consequences [52]. It is recommended that windsurfers hold the boom with their arms extended to avoid prolonged contraction of the biceps brachialis and brachioradialis muscles. In fact, maintaining the arm in a slightly flexed position for long periods may cause a LAC neuropathy due to the compression of the nerve under the sharp free margin of the biceps aponeurosis. Jablecki [51] reported the case of a 19-year-old woman who began experiencing pain and paresthesia in the right forearm after a prolonged windsurfing session. She presented decreased sensitivity to pin stimuli and tactile hypersensitivity in the distribution of the nerve. Radial forearm pain was evoked by full extension of the elbow while tenderness was elicited by a slight pressure applied laterally to the distal biceps tendon. Tinel's sign was absent. Deep tendon reflexes and muscle strength and a needle electromyography of the district muscles were normal leading to the diagnosis of LAC neuropathy. Symptoms were relieved following a short course of oral steroids. Despite maintaining a slightly reduced sensitivity on the radial aspect of the forearm, she was able to return to windsurfing without recurrence of pain or paresthesia.

21.5.3 Lower Limbs

In lower limbs, "front knee pain" is often reported in advanced windsurfers who sail at high speeds in conditions of short and irregular waves due to the knee joints being forced to absorb repeated impact with the water surface [20]. Overload syndromes of the lower limbs also include tibialis anterior and extensor digitorum tendinitis caused by poorly fitted or aligned foot straps. Many windsurfers prefer to fix their foot straps at the metatarsophalangeal joint level rather than at the mid-foot level because the former permits better control of the board.

In this position, however, the reaction force exerted on the foot by the foot strap is not only the result of dorsiflexion of the ankle, but also of an added dorsiflexion movement produced by the toe extensors at the metatarsophalangeal joints. This additional force increases the compression exerted by the strap on the toe extensor tendons at a time when these tendons are subject to tensile longitudinal stresses (Fig. 21.9). This may result in tendon irritation and inflammation.

Hetsroni et al. [53] reported two cases of Olympic-class world champions, one male and one female, complaining of painful swelling along the dorsum of the metatarsals of both feet. Ultrasound and MRI findings were consistent with tendonitis. Treatment included rest, nonsteroidal anti-inflammatory drugs, physiotherapy and coaching to position the strap at the mid-foot level instead of at the metatarsophalangeal joint level. Both athletes experienced complete resolution of symptoms and returned to full activity within 4–8 months.

21.6 Windsurfing Wound Treatment

Wounds caused by the edge of the board or the cutting edge of the keel fin during falls are specific to windsurfing and can be deep involving muscle layers [16]. Penetrating injuries may also be caused by contact with needlefish or shells and rocks on the sea floor [27]. In addition to mechanical injuries, some marine species including certain species of corals and sea urchins [13] can cause envenomations of varying severity, and contact with stonefish and certain varieties of jellyfish can be fatal [20]. The appearance of blisters before developing calluses is common on windsurfers' hands (rarely on feet), particularly when using boards with rough surfaces [14, 20].

All skin lesions require thorough cleaning, debridement, and disinfection with tetanus prevention in the case of deep wounds. Whenever foreign bodies or splinters are suspected, they should be located with plain radiographs or by ultrasound examination and be surgically removed.

Jellyfish stings are common occurrences when windsurfing. A correct approach requires scraping off any extra stinging cells with the edge of a card or knife. The wound should then be rinsed with warm water, and a cortisone cream should be applied.

All wounds require at least 14 days of rest from windsurfing. This recommendation is not always readily accepted by windsurfers who generally want to practice in the event of favorable wind conditions despite the fresh wound. Contamination by sand and water commonly causes infection of the wound, and patch covers are generally unhelpful coming loose due to frequent contact with water. *Duct tape* [3] is the only type of adhesive tape which is strong enough to hold a waterproof cover in place while windsurfing. It must be removed after each session and replaced by traditional medical plasters after would cleaning [20]. Surf shoes and gloves provide useful protection against wounds; however, some windsurfers complaint that they limit the sensitive feedback required to finely adjust technique in response to minimal variations in wind and wave.

21.7 Infectious Diseases

The practice of windsurfing is often tolerated in areas where bathing is not considered to be safe because of water pollution. According to Dewailly et al. [54] however, water pollution exposes windsurfers and swimmers to health hazards similarly due to frequent contact with the water. The authors documented the risks associated with windsurfing in sewage-polluted water during the Windsurfer Western Hemisphere Championship, held in Quebec City (Canada) in Baie de Beauport on the St. Lawrence River in 1984. Fifty seven percent

($n = 45$) of a total of 79 competitors reported at least one symptom associated with exposure to polluted water including gastrointestinal symptoms (nausea, vomiting, diarrhea, or abdominal pain), wound infections, localized erythema, otitis and conjunctivitis. There was a regular trend of risk increase, and it was proportional to the number of falls in the water; all those ($n = 10$) who fell into the water more than 30 times demonstrated these symptoms while less than half (44 %) of those who fell ten times or less did so. Relative risk was measured as the ratio of incidence among windsurfers and among staff controls. The overall relative risk was 2.9 while the relative risk for gastrointestinal symptoms was 5.5. Recreational windsurfers are at even greater risk than competitors since they fall much more often into water. Skin and ear infections were reported among amateurs also in the series by McCormick et al. [14] and by Hopkins and Hooker [23]. A simple means of prevention proposed against ear infections among windsurfers is the use of drops containing a 2 % acetic acid solution. Acidifying the pH of the ear canal may prevent the proliferation of bacteria, including the *Pseudomonas* species, [14].

A severe case of keratitis caused by *Acanthamoeba polyphaga* leading to a large abscess and ultimately requiring corneal transplantation was reported in a windsurfer in the Netherlands by Völker-Dieben et al. [55]. Ocular infection by *Acanthamoeba* is associated with exposure to contaminated lake or sea water, contact lens wearing and trauma [56]. It is rare, but it may lead to potentially devastating keratitis resulting in severe loss of vision. The possibility of such infections should be considered in the diagnostic workup of conditions affecting the eyes of windsurfers since diagnosis at an early stage is strongly associated with treatment outcome [57]. There is a high risk of secondary infection following trauma and penetrating injuries by marine animals; needlefish penetrating injuries in particular can lead to necrotizing fasciitis and even peritonitis if the rostrum penetrates the abdominal wall [27]. In marine-acquired infections, antibiotic treatment should also cover aquatic *Vibrio* species bacteria [27]. *Vibrio vulnificus* was found in the blood cultures of a windsurfer who was affected by ARDS and fasciitis necrosis in all four limbs after being struck by lightning while sailboarding and subsequently revived [58]. The patient recovered after antibiotic treatment and numerous fasciotomies.

21.8 General Prevention Strategies

Windsurfing should be practiced by healthy people that are able to swim. Any pre-existing health condition should be carefully evaluated before taking up the sport, and people with epilepsy should be discouraged from boardsailing since seizures may lead to drowning [14]. Windsurfing is physically demanding, and an adequate strength and endurance training program focusing primarily on the arm, trunk, and back muscles is recommended [19] as well as a complete warm-up before each session. Windsurfers should consider taking a break after 60 min of practice to minimize the risk of injuries due to tiredness and loss of concentration, especially when experimenting with difficult maneuvers [18].

Choosing the right size of board and sail to prevent "overpower situations", appropriate trimming of the sail, and proper equipment may help prevent injuries and create the best conditions to enjoy the sport [20]. Personal flotation gear is important to reduce the risk of drowning,as well as helping to avoid chest wall injuries caused by the boom. Its use is controversial among some expert wave riders, however, since it may makes ducking under oncoming waves impossible in the event of equipment loss and may hinder recovery of the equipment itself.

Sun exposure to the skin and eyes is a risk factor for skin cancer and melanoma, and the use of protective clothing (including sunglasses) and creams or lotions offering a high sun protection factor is recommended in windsurfing as well as other outdoor sports [14, 44].

Wetsuits which cover the whole body including neck and limbs offer protection against hypothermia, sunburn and stings from jellyfish and other marine species. Protective equipment should be adopted including a helmet and ear protection, although some boarders argue that such measures reduce sensitivity to slight variations in wind speed and direction. The sport's dependence on nature means that the ability to interpret weather conditions is necessary both for performance and safety reasons, and meteorological education is always provided to sailing school programs. Windsurfing should ideally be practiced under constant monitoring provided by trained lifeguards. In the event of an incident, prevention of hypothermia and immobilization of the spine and limbs, even if seemingly unnecessary, are the most important steps in minimizing any further injury [25].

Conclusions

Windsurfing is found to be safer than many other traditional and modern sporting activities including tennis, football, competitive cycling [15], alpine skiing [13, 23] and hockey [14]. Nevertheless, a wide range of injuries and illnesses have been reported in this sport including severe and life-threatening conditions [25]. Optimal sailing technique, appropriate physical preparation and equipment, careful choice of location to reduce any potential harm from the environment, and specialized assistance in case of need are probably the most effective tools in preventing injuries and illnesses in this sport. Improvements in technology are also needed mainly developing gear and clothing that protect the body without limiting sensitivity and feedback from the equipment, both essential elements to perfect control of a sailboard.

References

1. Professional windsurfers association; changes to PWA rule book (1.8); http://www.pwaworldtour.com/fileadmin/user_upload/Rule_changes.htm. Accessed Apr 2015.
2. Encyclopædia Britannica. http://www.britannica.com/EBchecked/topic/645252/windsurfing. Accessed Apr 2015.
3. Windsurfing International Inc. v Tabur Marine (GB) Ltd. [1985] RPC 59. http://slcc.strath.ac.uk/scotslawcourse/ip/ip/patent/windsurf.html. Accessed April 2015 from: http://web.archive.org/.
4. United States Patent Office. 1970; 3,487,800 Wind -propelled apparatus http://www.freepatentsonline.com/3487800.pdf. Accessed April 2015.
5. The Official Website Of The International Sailing Federation.Isaf.Com. http://www.sailing.org/classesandequipment/boards/index.php. Accessed Apr 2015.
6. International RS:X class association. http://www.rsx-class.com. Accessed Apr 2015.
7. Professional Windsurfer Association 2006 rule book. http://www.pwaworldtour.com/index.php?id=1373. Accessed Apr 2015.
8. International Speed Windsurfing Class Association. http://www.facebook.com/Speedworldcup. Accessed Apr 2015.
9. World Sailing Speed Record Council. 500 metre records. http://www.sailspeedrecords.com/records. Accessed Apr 2015.
10. UK Windsurfing Association. https://ukwindsurfing.com/news/2005/pwa-indoor-round-up/. Accessed April 2015.
11. The International Funboard Class Association. International Funboard Class Association Race Management Guideline 2013–2016; Slalom racing 2014:26. http://www.internationalwindsurfing.com/userfiles/documents/ifca_rm_guidelines_sept_2014.pdf. Accessed April 2015.
12. Fehske K, Felder JH, Meffert RM. Verletzungen im Windsurfen – eine aktuelle deutschlandweite. Injuries in Windsurfing – a German-wide survey. Erhebung Sport Ortho Trauma. 2010;26:14–9. doi:10.1016/j.orthtr.2010.02.040.
13. Nathanson AT, Reinert SE. Windsurfing injuries: results of a paper- and internet based survey. Wilderness Environ Med. 1999;10:218–25.
14. McCormick DP, Davis AL. Injuries in sailboard enthusiasts. Br J Sports Med. 1988;22(3):95–7.
15. Mettler R, Biener K. Athletic injuries in wind surfing. Schweiz Z Sportmed. 1991;39(4):161–6.
16. Salvi M, Velluti C, Concu A, Ariu U, Atzori A, Dessy D, Sichel G. Retrospective epidemiological evaluation of acute and overuse injuries of muscle and bone in windsurfers. J Sports Traumatol Relat Res. 1997; 19:30–7.
17. Prymka M, Plötz GMJ, JeroschJ. Verletzungsmechanismen bei Regattawindsurfern. Sportverl Sportschad. 1999;13:107–111.
18. Petersen W, Rau J, Hansen U, Zantop T, Stein V. Mechanisms and prevention of windsurfing injuries. Sportverletzung-Sportschaden. 2003;17(3): 118–12.
19. Dyson R, Buchanan M, Hale T. Incidence of sports injuries in elite competitive and recreational windsurfers. Br J Sports Med. 2006;40:346–50. doi:10.1136/bjsm.2005.023077.
20. Kristen KH, Syré CMS, Kröner A. Windsurfensportmedizinische Aspekte. Sport Orthopädie Sporttraumatologie. 2007;23:98–104. doi:10.1016/j.orthtr.2007.05.002.

21. Allen GD, Locke S. Training activities, competitive histories and injury profiles of elite boardsailing athletes. Aust J Sci Med Sport. 1989;21(2):12–4.
22. Gosheger G, Jagersberg K, Linnenbecker S, Meissner HJ, Winkelmann W. Injury patterns and prevention in World Cup windsurfing. Sportverletz Sportschaden. 2001;15:50–4.
23. Hopkins VL, Hooker RS. Conducting an analysis of windsurfing injuries. Physician Assist. 2002;8:21–5.
24. Penichet-Tomás A, Alonso-Fernández D, Gutierrez-Sánchez A, Andreu-Cabrera E, Suárez-Llorca C. Women sport injuries: a retrospective study of elite windsurfers. J Human Sport Exer. 2012;7(2):446–53.
25. Kalogeromitros A, Tsangaris H, Bilalis D, Karabinis A. Severe accidents due to windsurfing in the Aegean Sea. Eur J Emerg Med. 2002;9:149–54.
26. Habal MB. Athletic injuries caused by the new sport of windsurfing and proposed preventive measures. J Fla Med Assoc. 1986;73:609–12.
27. Rouvillain JL, Donica A, Gane C, Zekhnini C, Garron E, Uzel AP. Windsurfing hazard caused by needlefish. Eur J Orthop Surg Traumatol. 2013;23(2):295–7. doi:10.1007/s00590-012-1032-x.
28. Witt J, Paaske BP, Jorgensen U. Injuries in windsurfing due to foot fixation. Scand J Med Sci Sports. 1995;5:311–2.
29. Anderson JG, Bohay DR, Patthanacharoenphon GC, Ertl AM. Midfoot injuries. In: Philbin TM, editor. Sports injuries of the foot evolving diagnosis and treatment, vol. 7. New York: Springer; 2014. p. 71–2.
30. Chew NS, Lee J, Davies M, Healy J. Ankle and foot injuries. In: Robinson P(Eds). Essential radiology for sports medicine. New York: Springer; 2010. p. 49–87.
31. Bahel A, Yu JS. Lateral plantar pain: diagnostic considerations. Emerg Radiol. 2010;17:291–5. doi:10.1007/s10140-009-0855-1.
32. Nunley JA, Vertullo CJ. Classification, investigation and management of midfoot sprains: lisfranc injuries in the athlete. Am J Sports Med. 2002;30:871–8.
33. Stavlas P, Roberts CS, Xypnitos FN, Giannoudis PV. The role of reduction and internal fixation of lisfranc fracture-dislocations: a systematic review of literature. Int Orthop. 2010;34(8):1083–91.
34. Welck MJ, Zinchenko R, Rudge B. Lisfranc injuries. Injury. 2015;46(4):536–41.
35. Trevino SG, Kodros S. Controversies in tarsometatarsal injuries. Orthop Clin North Am. 1995;26:229–38.
36. Mitani G, Hirose H, Nakamura Y, Shimpuku E, Minezaki T, Mochida J. Lisfranc ligament injuries in windsurfers. J ASTM Int. 2006;7(3):JAI14200.
37. Jespersen S, Wettergren A. Shoulder dislocation caused by wind-surfing. Ugeskr Laeger. 1988; 150(33):1986.
38. Ditty J, Chisholm D, Davis SM, Estelle-Schmidt M. Safety and efficacy of attempts to reduce shoulder dislocations by non-medical personnel in the wilderness setting. Wilderness Environ Med. 2010; 21(4):357–61. doi:10.1016/j.wem.2010.06.010.
39. Lipman GS. The wilderness first aid handbook. Skyhorse Publishing, New York, USA, 2013.
40. Sadat-Ali M, Al-Awami SM. Wind-surfing injury to axillary artery. Br J Sports Med. 1985;19(3):165–6.
41. Sibilia K. Suprascapular nerve palsy in a young windsurfer. Physiother Sport. 1997;20:16.
42. Jablecki CK, Garner S. Neurological complications of windsurfing (sailboarding). Semin Neurol. 2000; 20(2):219–23.
43. Rosenbaum DA, Dietz TE. Windsurfing injuries: added awareness for diagnosis, treatment and prevention. Phys Sportsmed. 2002;30:15–24. doi:10.3810/psm.2002.05.280.
44. Ullis KC, Anno K. Injuries of competitive boardsailors. Physician Sports Med. 1984;12:86–93.
45. Dunkelman NR, Collier F, Rook JL, Nagler W, Brennan MJ. Pectoralis major muscle rupture in windsurfing. Arch Phys Med Rehabil. 1994;75(7):819–21.
46. Butt U, Mehta S, Funk L, Monga P. Pectoralis major ruptures: a review of current management. J Shoulder Elbow Surg. 2015;24:655–62.
47. Patel MK, Abbott RJ, Marshall WJ. Spinal cord injury during. Windsurfing Paraplegia. 1986;24:191–3.
48. Bahr R. No injuries, but plenty of pain? On the methodology for recording overuse symptoms in sports. Br J Sports Med. 2009;43(13):966–72. doi:10.1136/bjsm.2009.066936.
49. Locke S, Allen GD. Etiology of low back pain in elite boardsailors. Med Sci Sports Exer. 1992;24(9):964–6.
50. Ciniglio M, Maffulli N, Del Torto M. Transitory compression of the posterior interosseous nerve in windsurfers: a clinical and anatomical study. Ann Sports Med. 1990;5:81–4.
51. Jablecki CK. Lateral antebrachial cutaneous neuropathy in a wind- surfer. Muscle Nerve. 1999;22:944–5.
52. Campillo P, Leszczynski B, Marthe C, Hespel JM. Electromyographic analysis on a windsurfing simulator1. J Sports Sci Med. 2007;6:135–41.
53. Hetsroni I, Mann G, Ayalon M, Frankl U, Nyska M. Extensor digitorum longus tendonitis in windsurfing due to foot strap fixation. Clin J Sport Med. 2006;16:74–5.
54. Dewailly E, Poirier C, Meyer FM. Health hazards associated with windsurfing on polluted water. Am J Public Health. 1986;76:6.
55. Völker-Dieben HJM, Bos HJ, Kok-Van Alphen CC. Amoebic Keratitis in a Windsurfer. Nederland Tijdschrift Voor Geneeskunde. 1980;124:1147–51.
56. Jiang C, Sun X, Wang Z, Zhang Y. Acanthamoeba keratitis: clinical characteristics and management. Ocul Surf. 2015;13(2):164–8. doi:10.1016/j.jtos.2015.01.002.
57. Bharathi JM, Srinivasan M, Ramakrishnan R, Meenakshi R, Padmavathy S, Lalitha PN. A study of the spectrum of Acanthamoeba keratitis: a three-year study at a tertiary eye care referral center in South India. Indian J Ophthalmol. 2007;55:37–42.
58. Ulusarac O, Carter E. Varied clinical presentations of Vibrio vulnificus infections: a report of four unusual cases and review of the literature. South Med J. 2004;97(2):163–8.

Extreme Sailing Medicine

22

Injuries and Illnesses

Francesco Feletti and Andrea Aliverti

22.1 Introduction

The origins of sailing dates back to antiquity, and despite the passage of millennia, the sport retains its strong and characteristic relationship with natural elements. Technical and tactical skills play a crucial role, often more-so than general physical fitness. At the same time, sailing has greatly changed over time, especially over the last few decades, and it is still in tumultuous evolution. Technology plays an ever more important role (Fig. 22.1) while new equipment and race formats with an emphasis on speed and spectacular maneuvers continue to attract the attention of the media and general public.

These features allow modern sailing to be counted among other extreme sports. In particular, offshore sailing competitions which are held in hostile and unpredictable environmental conditions maintain the spirit of ancient pioneering expeditions while fleet regattas and match races are characterized by breathtaking and high-speed maneuvers. As sailboat performance advances, so does the demand for ever-greater physical and mental performance on the part of athletes. As a result, medical support such as advising on the choice of equipment and the most efficient safety systems, optimizing the athletic preparation of crew members, and the prevention and rehabilitation of any injuries and illnesses sustained becomes ever-increasingly important.

22.2 Sailing Injuries and Illnesses

Today, there is a wide range of ways to experience amateur and professional sailing, and event formats range from match races to fleet regattas and ocean races. The many sailing schools throughout the world allow the sport to be practiced safely at any age. Even amateur practice, which almost invariably represents the initial approach to this sport, may involve certain risks, especially if the appropriate precautions are not taken.

The significant differences among sailing classes require differentiated and targeted medical approaches. Indeed, in the Olympic classes and in the America's Cup, the high demands made on the athletes expose them to the risk of various and specific medical conditions that are

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Fig. 22.1 Open class "Clan des Team" at the Centomiglia del Garda regatta, Lake Garda, Italy. (Photo: Davide Casadio)

mainly linked to poor technical execution, overloading and fatigue. The America's Cup in particular places highly variable demands on sailors depending on their specific role requiring long preparation times and high workloads. Finally, in offshore sailing, the environmental conditions and demanding pace of life are highly stressful and need to be sustained over long periods. This leads to the onset of various injuries and illnesses almost always difficult to treat in remote areas far from medical access.

22.3 Recreational Sailing and Beginners

22.3.1 Injuries

Both recreational and novice dinghy sailors mainly report acute injuries [1, 2]. Schaefer studied injuries among 536 students enrolled in basic sailing courses in Kiel, Germany, and found an injury rate of 0.29 injuries per 1000 h of sailing [1]. Of 238 injuries, 39.5 % were to the upper limbs, 32.8 % to the head and neck, 26.5 % to the lower limbs, and only 0.8 % were to the back. Most of the injuries were bruises (55.1 %; $n=133$), abrasions (17.2 %; $n=41$) and cuts (14.3 %; $n=34$). Mainly sustaining cuts and lacerations, the hand was the most involved upper limb part in the vast majority of cases (88 %; $n=83$). More than a quarter of these injuries occurred while handling the sheet. Almost all head injuries were contusions from hitting the boom or the mainsheet during maneuvers or following a loss of control of the boat. Knee contusions mainly caused by contact with the hull (31.0 %; $n=9$), winches (20.7 %; $n=6$) or the dagger board case (20.7 %; $n=6$) were also common. The majority of injuries (40.7 %; $n=97$) were suffered by helmsmen and were related to the greater variety and complexity of the actions required by their role on board; bowmen were victims of about a quarter (26.5 %; $n=63$) of the injuries; and the remaining injuries were not specific to either of these roles. In wind speed range between 1 and 5 Bft, the higher the wind speed, the higher the risk of injury. Injuries among novices are more common when sailing in onshore wind; especially at sea, wind raises waves near the shore break rendering not only navigation difficult for inexperienced crews but also exit and reentry.

In their series of predominantly amateur sailors, Nathanson et al. [2] found an injury rate of 4.6 per 1000 days of sailing. The pattern of injury in dinghies and keel boats was similar: in dinghies, the lower extremities were more commonly affected (44 %) followed by the upper extremities (38 %) and head/neck (12 %), while in keel boats, most of the injuries were to the upper limbs (40 %), lower limbs (38 %), and trunk (11 %). Leg contusions were the most common injuries overall; knee contusions prevailed in dinghies while hand lacerations were among the most common injuries in keelboats, the main causes being entanglement in lines and collision with winches and cleats. Head, face, and eye injuries represented roughly 10 % of injuries both in dinghies and keelboats, and more than half resulted from impact with the boom and spinnaker pole, usually during maneuvers in heavy weather. Maneuvers such as tacking, jibing and sail changing were the root of injuries in about 40 % of cases in both dinghies and keel boats; the activities more often associated with injuries were crossing from one side of the boat to the other during maneuvers, operating a winch and steering. Most injuries were caused by falls, a sailor becoming caught in lines, or collisions with fellow crew members or objects such as a boom, spinnaker pole or sail clew. About half of the injuries were sustained in the cockpit in both keelboats and dinghies, while injuries occurring on the mid-ship prevailed in dinghies and on the foredeck in keelboats. Inclement weather was the most predominant contributing factor to injuries as it was involved in 19 and 23 % of injuries on dinghies and keelboats respectively.

22.3.2 Prevention

To avoid injuries among beginning and amateur sailors, the use of equipment that simplifies activities on board and increases safety may be the most effective strategy. This allows for a safe process of learning and practice. Sailboats should comply with certain medical and ergonomic guidelines especially when designed for beginners: rounded forms rather than sharp edges should be adopted especially for the deck and drift while cleats, winches, and bailers should be positioned in places with reduced likelihood of haphazard contact.

Impact with the boom or mainsheet is the most common cause of injuries among beginners (31.1 %; $n=74$) [1], and these consist almost exclusively of head lacerations and contusions. The most recent sail profiles provide a high degree of propulsion even with smaller sails allowing the boom to be mounted higher on the mast with no significant change to the center of effort and no increased risk of capsizing. This design change is particularly useful on boats adopted by sailing schools where maximum performance is not the main objective. Falls or tripping can be prevented by properly stowing equipment on board and by applying anti-slip paint to passageways.

Non-slip shoes and sailing gloves may prevent falls and hand injuries. Indeed, some of the most severe injuries on all types of boats are those to the hands (34.9 % of all injuries), and the use of hard-wearing, performance sailing gloves is particularly recommended to protect hands against both injury and atmospheric agents. Gloves are particularly important in cold climate conditions and when handling ropes under high tension, especially when trimming spinnaker sails (Fig. 22.2). To avoid abrasions and lacerations to the hands, shrouds and ropes should be of the highest caliber and should be changed regularly to assure they are always as smooth and soft as possible.

Life jackets should be worn at all times while sailing on any and all types of boats. The annual fatality for recreational sailors in 2012 in the USA was 0.35/100,000 participants. Drowning was the cause of 73 % of recreational boating deaths in the same year with most of the fatalities resulting from falls overboard (40.9 %) or capsizing (28.8 %). Furthermore, 77 % percent of sailors who drowned in 2012 in the USA were not wearing a life jacket [3] (Fig. 22.3).

Fatigue or trauma related to falls into water may compromise or reduce people's ability to bring themselves to safety and even to swim. In case of head injury followed by a fall in water, a life jacket with head support can protect against drowning. Despite all efforts by national federations and *World Sailing* (formerly known as ISAF – International Sailing Federation) to encourage their use in sailing schools and during regattas, many amateur sailors are still reluctant to wear life jackets. In the study by Nathanson et al. [2], only 30 % of amateur sailors wear a life jacket. However, there are a variety of products available

Fig. 22.2 Crew of a UFO 22 sailing on a beam reach. Bowman trimming spinnaker, wearing gloves (Photo: Davide Casadio)

Fig. 22.3 Open class "Raffica" at the Centomiglia del Garda regatta, Lake Garda, Italy. The boat capsized due to the breakage of the keel (Photo: Davide Casadio)

on the market now whose models suit all requirements and levels of experience from beginners to professionals.

22.4 Olympic Sailing

Sailing is one of the oldest sports in the Olympic program. It was first included in the 1900 Olympic Games. It made its next Olympic appearance in 1908 and has been part of every competition since. Today, the Olympic classes include single-handed dinghies (Finn, Laser, and Laser Radial), double-handed dinghies (470), sailboards (RS:X), a multihull class (Nacra 17) and skiffs (49er and 49er FX) (Fig. 22.4) [4].

22.4.1 Injuries

Using a questionnaire, Legg et al. [5] found an incidence of 0.2 injuries/athlete/year among 28 elite New Zealand Olympic-class sailors. Out of 380 sailing athletes competing at the London Olympic Games [6] (27 July – 12 August 2012), 56 (14.7 %) sustained injuries requiring medical

Fig. 22.4 49er is the two-handed skiff-type high-performance Olympic Class. It is powered by a main sail, jib, and 37.16 m^2 triradial asymmetric spinnaker, and both of the crew members are equipped with their own trapeze. The class has been in every Olympic Games since its debut in Sydney, 2000 (Photo: Davide Casadio)

attention, mainly to the lower limbs (34 %) and trunk (28.5 %), with the thoracic and lumbar spine being involved in 19.6 % of the injuries, followed by the upper limbs (25 %) and the head/neck (7.1 %). Most of the injuries (28.6 %) were muscular injuries (strains, ruptures, or tears), contusions (12.5 %; $n = 7$), and sprains (10.7 %; $n = 6$).

A study on young Swedish Olympic-class sailors confirmed that lower limbs were the main body part affected by injuries (43 %), the knee being the most commonly reported injury location (19 %) [7]. Among national elite sailors taking part in the Pre-Olympic Sailing Week, the most reported diagnostic muscular injuries were to the back and knee (Ruschel et al. [8]). Olympic-class athletes appear to be more prone to overuse injuries than to sudden onset injuries [6, 8]. Injuries in these athletes are often caused by a poor balance between work and recovery time [8–10]. These Olympic sailing classes also require athletes to maintain unnatural positions (hyperextension, locking, or twisting) for long periods to optimize the trim of the boat resulting in postural overloading and stress to joints.

Fig. 22.5 Hiking on a laser (Photo: Davide Casadio)

Hiking is a practice consisting of the crew leaning over the side of the boat maintaining their hold using toe straps for the purpose of counter balancing the wind heel force in order to increase the speed of the boat. Hiking is practiced on single-handed dinghies (Laser, Finn, and Laser Radial), and it is associated with overuse injuries to the knees and back [5, 11–14].

The hiking technique differs among classes: in laser sailing (Fig. 22.5), the straight-leg position creates a load moment both on the lumbar spine and the knee, while in Finn, the hiking position with not completely extended legs increases the shear force acting on the knee [10, 14]. Chronic knee pain associated with chondromalacia patella may arise as a consequence of an incorrect foot position under the foot straps with the leg in internal rotation. This causes the load to move on the vastus lateralis muscle which, over time, is prone to develop to a greater extent compared to the other heads of the quadriceps femoris thereby predisposing it to excessive lateral patellar compression syndrome [14].

In elite dinghy sailors, hiking may also cause an imbalance in the hamstring/quadricep strength ratio impairing the stability of the knee joint against anterior-posterior shear forces and bone-on-bone stress forces [14–16]. Another problem due to hiking is iliopsoas overload causing hyperlordosis characterized by high compression forces on the spine at a time when it is also subjected to shear force. This potentially leads to chronic injuries [14]. Overloading of the upper limbs (elbows and shoulders in particular) is also common among elite athletes involved in Olympic-class competitions due to the need for frequent adjustment of the mainsheet especially on heavier boats and when sailing in more strenuous conditions [7].

22.4.2 Prevention

Knee cartilage injury following prolonged hiking is potentially serious and may require surgical repair [2]. Knee and lower back overuse injuries should therefore be prevented by improving technique, optimizing posture, and gradually training strength [12]. In all Olympic classes, a proper training regime to prevent injuries should include a strengthening of synergist and joint-stabilizing muscles along with core stability and proprioceptive training. Specific training should also be undertaken depending on the particular sailing class. In those involving hiking, strengthening of the femoral quadriceps and abdominal muscles has a direct effect on performance. It is also important to prevent any muscle imbalances and articular misalignment by way of appropriate exercises for hamstring and lumbar muscle strength and flexibility. In Olympic-class sailors, 30 % of injuries were related to physical training, the majority occurring at the beginning of the sailing season. Programs should therefore be tailored to specific individual physical characteristics, and an appropriate training plan ensuring a gradual transition to the sailing season may contribute to injury prevention [7]. The transition of young sailors from the smaller Optimist dinghies to the more demanding Olympic classes is a particularly critical phase that should be accompanied by proper preparation to improve technique, muscle strength and proprioception.

22.5 America's Cup

America's Cup is the world's most famous sailing and the oldest international sporting trophy. It is governed by several rules and documents, and the permitted boat models change from one competition to the next. The 33rd challenge was the first to include multihulls while the 34th was held with AC72 (America's Cup 72 class) catamarans with an overall length of 26.2 m (86 ft) and a crew of eleven people. These craft are powered by a 131-ft carbon wing and skim above the water on hydrofoils enabling them to sail at speeds well over 40 knots (74 km/h, 46 mph) (Fig. 22.6).

AC48s are the permitted wing sail catamarans in the upcoming 35th challenge. They feature a length of 14.65 m (48.1 ft.), a maximal air draft of 24.9 m (81.7 ft.) and a six-man crew [17]. The challenger team in the America's Cup is the winner of a selection series called the Louis Vuitton Cup. The preparation for the America's Cup involves a challenging program of training over a period of 2–4 years, during which the crew is involved in both land-based activities and on-water sailing for 9–13 h a day [18].

22.5.1 Injuries

In a study on 35 sailors during the preparatory phase and holding of the 2003 America's Cup, Neville et al. found an injury rate of 5.7 injuries/1000 h. The overall number of injuries in training and sailing were similar, but given that the time spent sailing was three times more than that spent training, the incidence of injury during training was approximately four times higher (8.6/1000 training hours) than during sailing (2.2/1000 sailing hours). Injury incidence and patterns depend on crew roles; particularly when including both land-based activities, and weight training, grinders have a higher risk of injuries (7.7/1000 h) due to significant strength and power requirements. Considering sailing only, the crew role suffering the highest incidence of injury is that of bowmen (3.2/1000 h). This post requires high-intensity activity that is carried out in the most highly unstable area of the bow [18, 19].

Fig. 22.6 US Oracle Team practices in training races on the Louis Vuitton Cup course in San Francisco, 21/8/2013 (Photo: Chris Cameron)

Fig. 22.7 Onboard Emirates Team New Zealand AC72, NZL5 during testing June 14, 2013. Helmsman steering and crew-members sail trimming, grinding, and top-handle winching shown (Photo: Chris Cameron)

The most affected body parts were upper limbs (40 %), lower limbs (25 %), trunk (20 %), and head/neck (14 %) [19]. Although there is contrasting data as to whether acute or overuse injuries are more common in the America's Cup, overuse injuries were more severe than acute ones in terms of days of absence from training and sailing activities [19, 20]. Hiking is not practiced on boats participating in the America's Cup, hence, crew-members are not subjected to back and knee overuse problems that are typical of dinghy sailors [19]. However, high-repetition activities such as grinding, top-handle winching, sail trimming and steering place intensive demands on upper limbs (Fig. 22.7).

As a result, shoulder and upper arm overuse injuries including long head of biceps tendinopathy, elbow flexor/extensor tendinosis, and entrapment of the posterior interosseus nerve (PINE) accounted for 40 % of the reported injuries. PINE in particular was attributed to overloading of the supinator muscle while pulling sails and grinding [19]. More generally among the America's Cup sailors, local tenderness near the elbow and forearm due to the aforementioned conditions has been referred to as "grinder's elbow" [21].

Lumbar spine and thoracolumbar junction sprains were the main cause of absence from training and sailing. In particular, muscle contractures of the quadratus lumborum, trapezius and rhomboid are particularly common among more physically demanding roles such as grinders, bowmen and mastmen [5, 13, 15, 16, 18]. Furthermore, thoracolumbar spine facet joint sprains as well as spinal degenerative changes are precipitated by the repetition of movements involving a forward flexed and rotated position of the spine while grinding, pulling ropes and handling sails [19].

Cervical problems, on the other hand, are mainly attributed to the protraction and extension of the cervical spine maintained at length by trimmers while looking up at sails and by helmsmen while steering. A program of preventive physiotherapy incorporating neuromuscular and proprioceptive techniques proved to be highly effective in preventing overuse injuries. Among grinders, it was effective in lowering the incidence of these injuries from 78 to 20 % [22, 23]. Contusions and sprains were the most common acute injuries, the main mechanism of injury being the impact with objects or hardware on or above the deck such as winches, winch handles, spinnaker poles, ropes, foot chocks or sails [9, 11, 19, 20]. The most effective measures in preventing acute injuries therefore include the adoption of ergonomically designed equipment and optimal setup of the America's Cup race yacht decks.

22.5.2 Fatalities

While the America's Cup itself has not yet suffered any fatalities, two deaths have been reported during training [24]. In the first case, a sailor died in 1999 during training for the regatta after being hit in the head by a broken piece of equipment [24]. The second occurred in May 2013, when Artemis Racing's AC72 pitchpoled (somersaulted) and broke apart while practicing for the 34th challenge resulting in the death of a crew member who suffered from blunt trauma, serious head injuries and cuts, and drowned after becoming trapped underwater. Another crew-member suffered from minor injuries in the same incident [25]. The incident prompted the race organizers to implement safety recommendations in addition to the crash helmets and life vests already used to include body armor, an air tank with breathing tube and underwater locator devices [26]. Doubts have also been raised as to the safety of the AC72s, some of the fastest sailboats ever built. Indeed, this was not the first AC72 to capsize – the Oracle Racing team's AC72 capsized in October 2012 after pitchpoling. Although the boat suffered severe damage, no crew-members were injured on that occasion [24].

22.5.3 Illnesses

Illnesses account for 35 % of all health problems suffered during the America's Cup, the majority consisting of upper respiratory tract infections (40 %) followed by stress-related disorders such as hypertension and insomnia (13 %). The high incidence of upper respiratory tract infections has been associated with a weakening of the immune system due to intense training, psychological stress and cold and damp conditions. To prevent these infections, it is crucial to ensure an adequate, balanced diet that maintains a positive energy balance and guarantees an adequate intake of carbohydrates, proteins and micronutrients [19, 27]. Stress levels should also be monitored by assessing markers of tiredness and overtraining. Neville and coworkers measured s-IgA concentration in saliva samples from 38 athletes taken over 50 weeks of training preceding the 32nd America's Cup in Valencia, Spain in 2007. The results led the authors to suggest that, despite the wide individual variability in the basal values of s-IgA, regular monitoring of resting s-IgA together with a simple fatigue questionnaire may benefit athletes and coaches in determining the risk of upper respiratory tract infections and fatigue [28].

22.6 Offshore Sailing and Ocean Races

Offshore sailing includes both cruising and racing over long distances and on open water, while ocean races are defined as offshore races with a length of more than 800 miles [4]. Today, *World Sailing* recognizes seven major oceanic events of different formats ranging from non-stop to multiple-leg events completed single-handedly or involving crews on mono and multihulls. The Transat is the oldest solo ocean race and, today four classes of yacht compete in this race, namely: Ultimes, Multi50s, IMOCA60s and Class40s [4]. The 'Route du Rhum' is a single-handed, offshore race from Saint-Malo in France to Pointe-à-Pitre in Guadeloupe, and it is open to monohulls and multihulls [33]. The Transat Québec–Saint-Malo is the only continuous west-to-east offshore, crewed race [30]. The remaining events are all round-the-world races: the nonstop Barcelona World Race starts and finishes in Barcelona and is sailed by two-man crews on Open 60 IMOCA monohull boats [29]; the Vendée Globe is a round-the-world single-handed yacht race taking place every 4 years, sailed non-stop and without assistance [31]; and the Velux 5 Oceans Race is a single-handed round-the-world yacht race sailed in stages [34]. The Volvo Ocean Race (formerly the Whitbread Round the World Race) is a multi-leg yacht race around the world held every 3 years. Beginning with the 2014–2015 edition, it is sailed on the new Volvo Ocean 65 one design. Each standard team is composed of eight professional sailors plus one non-sailing multimedia reporter onboard while women's teams can race with 11 sailors plus one non-sailing multimedia reporter [32].

Apart from the aforementioned events all in compliance with *World Sailing* Major Oceanic Event status, there is a wide variety of other offshore and oceanic competitions. The famous offshore Fastnet Race takes place every 2 years over a course of 608 nautical miles. It starts from Cowes on the Isle of Wight, rounds the Fastnet Rock off the southwest coast of Ireland, and finishes in Plymouth [35]. Held in August, the succession of low-pressure systems advancing on the British Isles from the North Atlantic Ocean provides constantly moving weather conditions, therefore, skilled interpretation and optimal exploitation of weather conditions are crucial to success in the race.

The BT Global Challenge round-the-world yacht race was unusual as it gave paying amateur crew members the chance to sail around the world on one-design steel yachts provided by the organizers. It was also held along the *westabout route* against prevailing winds and currents – the so-called wrong way. Although no longer staged, the same philosophy (crews consisting of paying, non-professional sailors) is reflected in the Clipper Round-the-World Race, but this regatta uses lighter, faster boats and the route follows the prevailing currents and winds [36].

22.6.1 Injuries

Trauma is one of the worst-case scenarios in a remote setting since the lack of appropriate equipment and supplies renders proper treatment difficult and evacuation procedures are long and complex [37]. Injury rates of 1.5 injuries per person per round-the-world race and 3.2 injuries per person per race have been reported in amateur and professional ocean racing respectively [38, 39]. Injuries in offshore sailing most commonly involve the upper (35 %) and lower limbs (35 %) followed by the chest (14 %) and the head/neck (13 %) [40]. In the upper limbs, hands are the most frequently affected (70 %), and hand injuries are most often caused by deck equipment incorporating mobile parts (pinch points) such as pulleys, winches, windlasses and trolleys [41]. The majority of lower limb injuries involve sprains, fractures and bruises to the ankle and foot. Chest injuries such as collarbone fractures and fractures and bruises to the rib cage are common in heavy weather conditions [38, 40]. Head injuries are mainly caused by the boom, spinnaker or jockey poles and may be accompanied by

Fig. 22.8 Alicante, Team Vestas Wind at the start of the Volvo Ocean Race 2014–15. Now in its 12th edition, the route requires a truly global circumnavigation – 38,739 nautical miles from Alicante (ESP) to Gothenburg (SWE) over 9 months of racing [26] (Photo: Davide Casadio)

facial and spinal fractures. A comparison between the professional Whitbread Round the World Race regatta (now the Volvo Ocean Race, Fig. 22.8) and the amateur British Telecom Round the World Yacht Race reveals a lower number of serious injuries among amateur sailors but a higher number of minor injuries [38, 41].

These differences between professionals and amateurs can be attributed to better balance and physical fitness and sharper instinctive-type reflexes among professional sailors. Amateur ocean yacht races have nevertheless been shown to have a "learning curve" with a progressive reduction in the number of injuries between the initial and the final parts of the regatta taking weather conditions into account [38].

Acute injuries increase in strong winds and rough seas, and the foredeck, galley, winches and helm have been identified as hazardous areas in this respect [38, 42]. An important difference between professional offshore and ocean yacht racing and other sailing classes is that a considerable percentage of injuries (33 %) occur below deck. It is here that the crews spend most of their time, and violent and sudden movements may cause falls and impacts with hard surfaces [38]. Overuse injuries include rotator cuff injury, inflammation of the elbow ("winch elbow"), cases of olecranon bursitis (some complicated by damage to the ulnar nerve [38, 43, 44]), and sciatic and lower back pain [40] (Fig. 22.9). In professional offshore racing, the demands of steering in heavy weather conditions make helmsmen particularly prone to injuries and, in particular, to developing upper extremity overuse problems such as rotator cuff impingement, wrist tenosynovitis and carpal tunnel syndrome [39]. These

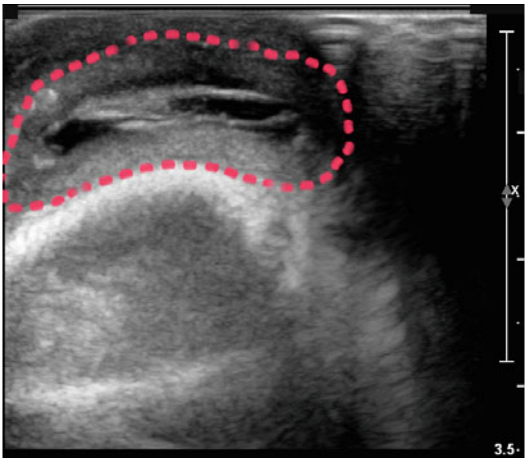

Fig. 22.9 Olecranon bursitis. Echographic diagnosis. The dotted circle highlights the thickened fluid filled bursa

were particularly associated with an upper limb dominant steering technique and the use of polished carbon steering wheels (whose smooth surface may require a higher grip force and lead to forearm stress, particularly when wet) as opposed to fabric grip wheels [14].

22.6.2 Illnesses

In offshore yacht racing, illnesses represent a large proportion (56 %) of medical conditions [38, 39, 41]. According to Price et al., these illnesses most commonly affect the urinary and gastrointestinal tract (22.5 %), skin (21.2 %), and upper respiratory tract (13.2 %). Other problems include seasickness (15.5 %), neurological problems (4.4 %), dental problems (4.1 %, including gingivitis, decay, and dental injuries), and eye problems (3.6 %). Cases of middle ear infections and earwax were also reported [38]. Heat and damp, salt encrustation (especially in the neck and wrist seals of dry suits), oilskin chafing, and limited freshwater supplies increase the risk of dermatological problems, particularly boils and eczema, while crowding on board encourages the transmission of upper respiratory tract infections.

Despite the fact that crews were reasonably conscientious at adopting sun protection measures with almost all members wearing hats (80 %) and protective creams (70 %), and the fact that many boats are equipped with purpose-built canopies (bimini tops and companionway sea hoods) to reduce sun exposure on long crossings, the authors report cases of burns directly attributable to solar radiation including first- and second-degree burns and actinic dermatitis [40]. There are also reports of burns caused by ropes, accidental scalding while heating liquids, and skin lesions from contact with marine animals. Any skin lesion must be immediately disinfected and dressed regularly to prevent serious infections, especially in tropical areas. Staphylococcus infections are common, and there have been cases of septic arthritis following untreated boils on the front of the knee [38, 40, 41]. It is important to protect the eyes from the sun and from high-velocity spray so as to prevent conjunctivitis [38]. Price et al. also reported some neurological problems including migraine; among them, a case of traumatic lesion of the posterior interosseus nerve resulting from a contusion caused by a flogging sheet while tacking, and one case of benign paroxysmal positional vertigo following head injury. The same study [38] also reports a psychiatric case of "deck fright" characterized by a fear of being on deck especially at night following a heavy storm on the Southern Ocean. During long crossings, seasickness is generally only a problem during the first 72 h after which the majority of crew-members adjust to the movement.

22.6.3 Prevention

Great attention must be paid to prevention in offshore sailing since bringing a crew in difficulty to safety is potentially a long and complicated process. No longer the domain of young, professional crews, ocean regattas are becoming increasingly accessible to enthusiasts of many different ages of both sexes. Chronic fatigue may initiate the onset or aggravation of various conditions, and those who intend to take up offshore sailing are advised to undergo a thorough medical checkup. Proper equipment and clothing are essential. Protective headgear in particular should always be adopted to avoid head trauma due to moving spars. Hypothermia, although infrequent, is extremely dangerous. A chilled body is also more susceptible to injury of joints, tendons and muscles. Waterproof garments are especially effective in reducing heat dispersion particularly in inclement weather and are effective at preventing muscle tears and bursitis in the joints of the lower limbs [38]. During solo races, severe fatigue and substantial sleep loss are correlated to incidents of technical oversight during maneuvers. Safety margins could be improved by increasing and better managing periods of sleep and rest [45, 46].

Many useful technological innovations are now available to meet the unique needs of sailors on solitary or long-distance crossings. Automatic defibrillators for nautical use can be operated by people with no medical training while small emergency kits can render limited quantities of seawater fit for drinking under an extreme circumstance such as a shipwreck. Emergency locator transmitters (ELTs) such as emergency position indicating radio beacon (EPIRB) and personal locator beacon (PLB), interface with the Cospas-Sarsat satellite system and allow sailors to immediately signal their position from any location in an emergency. They are included in the safety equipment listed by the *World Sailing* Offshore Special Regulations [4]. These devices can be activated manually or automatically (following immersion or collision) to signal the victim's position to rescue coordination centers making them a fundamental ally in search and rescue operations [47]. Telemedical assistance services using telecommunication and information technologies allow medical assistance by specialists to be provided anywhere in the world. These services also allow a personal medical file to be set up prior to departure allowing more targeted and rapid assistance as necessary.

References

1. Schaefer O. Injuries in dinghy-sailing – an analysis of accidents among beginners. Sportverletz Sportschaden. 2000;14:25–30.
2. Nathanson AT, Baird J, Mello M. Sailing injury and illness: results of an online survey. Wild Env Med. 2010;21:291–7.
3. Nathanson A. Sailing injuries. Ist International Extreme Sports Medicine Congress. Boulder, Denver; 2014.
4. The official website of the International Sailing Federation. www.sailing.org/. Accessed On Jun 2015.
5. Legg SJ, Smith P, Slyfield D, Miller AB, Wilcox H, Gilberd C. Knowledge and reported use of sport science by elite New Zealand Olympic class sailors. J Sports Med Phys Fitness. 1997;37(3):213–7.
6. Engebretsen L, Soligard T, Steffen K, Alonso JM, Aubry M, Budgett R, Dvorak J, Jegathesan M, Meeuwisse WH, Mountjoy M, Palmer-Green D, Vanhegan I, Renström PA. Sports injuries and illnesses during the London Summer Olympic Games 2012. Br J Sports Med. 2013;47:407–14. doi:10.1136/bjsports-2013-092380.
7. Bøymo-Having L, Grävare M, Silbernagel KG. A prospective study on dinghy sailors' training habits and injury incidence with a comparison between elite sailor and club sailor during a 12-month period. Br J Sports Med. 2013;47(13):826–31. doi:10.1136/bjsports-2012-091841. Epub 2013 May 14.
8. Ruschel C, de MF S, Haupenthal A, Hubert M, Schütz GR, Cerutti PR, Matheus PS, Roesler H. Incidência de lesões em velejadores brasileiros de diferentes níveis técnicos. Revista Brasileira de Medicina do Esporte. 2009;15(4):268–71.
9. Allen JB. Sports medicine and sailing. Phys Med Rehabil Clin N Am. 1999;10(1):49–65.
10. Mackie H, Sanders R, Legg S. The physical demands of Olympic yacht racing. J Sci Med Sport. 1999; 2(4):375–88.
11. Allen JB, De Jong MR. Sailing and sports medicine: a literature review. Br J Sports Med. 2006;40:587–93. doi:10.1136/bjsm.2002.001669.
12. Shephard RJ. Biology and medicine of sailing. An update. Sports Med. 1997;23:350–6.
13. Blackburn M. The stayed back: ideas and exercises to avoid problems with the sailing spine. Aust Sailing. 1994;43–5:67.
14. Neville V, Folland JP. The epidemiology and aetiology of injuries in sailing. Sports Med. 2009;39(2):129–45.
15. Bojsen-Møller BJ, Larsson B, Magnusson SP, Aagaard P. Yacht type and crew-specific differences in anthropometric, aerobic capacity, and muscle strength parameters among international Olympic class sailors. J Sports Sci. 2007;25(10):1117–28.
16. Aagaard P, Beyer N, Simonsen EB, et al. Isokinetic muscle strength and hiking performance in elite sailors. Scand J Med Sci Sports. 1998;8(3):138–44.
17. America's cup event authority. America's Cup Class Rule Version 1.0. 31 Mar 2015. http://ac.mueva.eu/media/files/m377_ac-class-rule-v1.pdf. Accessed on Jun 2015.
18. Hadala M, Barrios C. Sports injuries in an America's Cup yachting crew, a 4 -year epidemiological study covering the 2007 challenge. J Sports Sci. 2009;27(7):711–7.
19. Neville V, Molloy J, Brooks J. Epidemiology of injuries and illnesses in America's Cup yacht racing. Br J Sports Med. 2006;40:304–11.
20. Allen JB. Sports medicine injuries in the America's Cup 2000. In: Legg SJ, editor. Human performance in sailing conference proceedings: incorporating the 4th European Conference on Sailing Sports Science and Sports Medicine and the 3rd Australian Sailing Science Conference. Palmerston North: Massey University; 2003. p. 45–6.
21. Miller C. Treating the America's Cup sailors. Phys Sportsmed. 1987;15:172–8.
22. Hadala M, Barrios C. Different strategies for sports injury prevention in an America's Cup yachting crew. Med Sci Sports Exerc. 2009;41(8):1587–96. doi:10.1249/MSS.0B013e31819c0de7.
23. Olsen OE, Myklebust G, Engebretsen L, Holme I, Bahr R. Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. BMJ. 2005;330:449.
24. Elias P, Wilson B. British sailor dies during America's Cup practice. 10 May 2013. Associated Press. http://www.ap.org/. Accessed on Jun 2015.
25. Huet H. Death cause for cup sailor: head trauma, drowning. SF Gate: San Francisco Chronicle. 15 Oct 2013. www.sfgate.com/sports/article/Death-cause-for Cup-sailor-head trauma-drowning-4898268.php. Accessed on Jun 2015.

26. CNSNews.com. Report: America's Cup sailor died of blunt trauma. 15 Oct 2013. http://www.cnsnews.com/news/article/report-americas-cup-sailor-died-blunt-trauma. Accessed on Jun 2015.
27. Gleeson M. Biomechanical and immunological markers of over-training. J Sports Sci Med. 2002;1:31–41.
28. Neville V, Gleeson M, Folland JP. Salivary IgA as a risk factor for upper respiratory infections in elite professional athletes. Med Sci Sports Exerc. 2008;40(7):1228–36. doi:10.1249/MSS.0b013e31816be9c3.
29. Barcelona world race. 2014–2015. http://www.barcelonaworldrace.org/en/.
30. Transat Québec-St Malo. http://www.transatquebecst-malo.com/.
31. Tour du Monde- en solitaire sans escale et sans assistance. 2016. http://www.vendeeglobe.org/fr/.
32. Volvo ocean race – round the world. http://www.volvooceanrace.com/en/home.html.
33. Route du Rhum. Destination Guadeloupe. http://www.routedurhum.com/.
34. Velux 5 oceans. http://www.velux5oceans.com/.
35. The world's biggest offshore race. http://fastnet.rorc.org/news-2015/press-releases-2015/the-worlds-biggest-offshore-race.html; https://www.clipper-roundtheworld.com/.
36. A race without equal. https://www.clipperroundtheworld.com/about/about-the-race.
37. Nicol ED. Medical support on a trans-atlantic sailing expedition. J R Army Med Corps. 2001;147:351–6.
38. Price CJS, Spalding TJW, McKenzie C. Patterns of illness and injury encountered in amateur ocean yacht racing: an analysis of the British Telecom Round the World Yacht Race 1996–1997. Br J Sports Med. 2002;36:457–62.
39. Spalding T, Malinen T, Tomson M. Analysis of medical problems during the 2001–2002 Volvo Ocean Race. NZ J Sports Med. 2005;34:56–60.
40. Rouvillain JL, Mercky F, Lethuillier D. Injuries on offshore cruising sailboats: analysis for means of prevention. Br J Sports Med. 2008;42:202–6.
41. Bugge M. The third Whitbread Round the World Race. Injury. 1986;17:196–8.
42. Laven K, Gilmour R. Volvo Ocean Race: the injuries stack up ... knife wounds, tooth loss, popped shoulders and broken ankles. The Telegraph 05; 2012. http://www.telegraph.co.uk/sport/othersports/sailing/volvo-ocean-race/9254794/Volvo-Ocean-Race-the-injuries-stack-up-...-knife-wounds-tooth-loss-popped-shoulders-and-broken-ankles.html. Accessed on February 2016.
43. Yazyhov V. Seahorse international. Sailing. 1999;228:42.
44. Goss P. Close to the wind. London: Headline; 1998.
45. Hurdiel R, Monaca C, Mauvieux B, McCauley P, Van Dongen HPA, Theunynck D. Field study of sleep and functional impairments in solo sailing races. Sleep Biol Rhythm. 2012;10:270–7.
46. Theunynck D, Hurdiel R, Pezé T, Estruch X, Bui-Xuân G. Sommeil et course au large en solitaire: comportements des coureurs et étude de faisabilité d'un «agenda interactif de sommeil. Pistes 2010;251:12. Retrieved from: http://www.pistes.uqam.ca/v12n2/articles/v12n2a4.htm.
47. International Cospas-Sarsat Programme. International COSPAS -SARSAT. http://www.cospas-sarsat.org/en/operatons/operations-concept/what-happens-when-i-activate-my-beacon. Accessed on Jun 2015.

White-Water Paddlesport Medicine

23

Canoeing, Kayaking and Rafting

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23.1 White-Water Paddlesports

White-water paddlesports involve paddling, canoes, kayaks or rafts on white-water for recreation and competition. Accidents and injuries in white-water paddlesports are relatively rare, but due to the unpredictable nature of the white-water environment, the consequences can be severe. This chapter will provide an overview of injuries and ill health associated with white-water paddlesports and methods of preventing and treating such injuries and illness. Below are some key terms which will recur throughout the chapter.

23.1.1 Key Terms

- *Paddlesports* – The overall term used to encompass all activities of canoeing, kayaking and rafting.
- *Paddlers* – The unspecific term for participants of all canoeing, kayaking and rafting activities.
- *Canoeing* – The umbrella term for canoe and kayak activities
- *Canoe* – A craft which is typically knelt and propelled by a single-bladed paddle
- *Kayak* – A craft which is propelled with a double-bladed paddle from a seated position
- *Raft* – An inflatable craft generally propelled by multiple individuals from a seated position, using a single-bladed paddle
- *Raft guide* – The professional who controls the raft allowing individuals with limited experience of white-water to participate
- *Defensive swimming* – A swimming strategy to minimise the chance of injury, where the swimmer is supine, facing downstream and thus travelling feet first

Although canoeing is an umbrella term for canoe and kayak activities, for accuracy, the terms canoeing and kayaking will be specifically used in this chapter.

23.1.2 The Evolution of White-Water Paddlesports

The development of white-water paddlesports originated with the navigation of upland European rivers during the late nineteenth and early twentieth centuries. A wild-water race on the River Isar in Germany between 16 and 17 July, 1921, was the first documented competition. Canoe slalom developed rapidly, with its first recorded race in 1933 on the River Aar in Switzerland, followed by its first World Championships 16 years later in Geneva. Canoe slalom is the only white-water paddlesport incorporated in the Olympic Games,

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Table 23.1 International scale of river difficulty [1, 2]

Grade	Definition
I	Low-difficulty river where little training is needed. Flow is slow moving and predictable. Obstacles are unobtrusive and easily negotiated. Self-rescue is easy with little risk to the swimmer
II	Moderate difficulty river with faster flow. Rapids are straightforward and easy to negotiate with training. Rapids are small–medium sized and routes are clear and visible. Group-assisted rescue is beneficial but not required. Swimmers are rarely injured
III	Difficult river with fast flow. Rapids are irregular and can swamp or even hold craft. Complex manoeuvres may be required to negotiate rapids and obstacles. With training, hazards which may be present, such as large waves and strainers, can be avoided as routes are recognisable. Self-rescue is still possible, although to avoid long swims, assistance is required. Risk to health is still limited
IV	Very difficult, intense, powerful water. Rapids can be large and unavoidable, or steep and narrow, requiring precision to manoeuvre down the fast flow. Inspection before attempting is recommended, particularly for the first time. Hazards and obstacles are numerous, some below the surface, increasing the risk of injury to simmers. Practiced group rescue is often essential. A strong Eskimo roll, to avoid requiring rescue, is highly recommended
V	Extremely difficult river with long, obstructed and violent rapids. Characteristics include large drops, unavoidable waves and holes or steep, complex chutes which require high levels of precision and fitness from the paddler. Inspection is required but may be difficult. Swims are very dangerous, with a high risk of injury and even death. Rescue support is essential but may be difficult, even for experts
VI	High-risk rivers which are generally classed as un-runnable. High risk of injury to the participant. Requires scouting before attempting. This is for experts only. Portaging is highly recommended

with its first appearance at the 1972 Games in Munich and being a regular event since Barcelona 1992. Paddling has been used to explore many rivers, some in remote and extreme locations all over the world. Due to the varying difficulties of different rivers, an International Scale of River Difficulty, used to classify individual rapids ranging from grade I to VI, has been developed (Table 23.1).

Table 23.2 Competitive white-water paddlesport disciplines

Discipline	Description
Slalom (Fig. 23.2a)	A race where gates are negotiated down a course in the fastest possible time. Penalties are incurred for touching or missing gates in the course
Freestyle (Fig. 23.2b)	Competitors complete various acrobats and manoeuvres on a single water hydraulic on a river. Points are scored for complexity and success of completion of manoeuvres
Wild-water racing	Negotiating a stretch of river in the fastest possible time. Two main types include an endurance race and a sprint race
Surf/ waveski	Similar to freestyle where acrobatics and manoeuvres are completed; however, these are completed on ocean waves. Points are gained for the complexity and success of completing manoeuvres
Raft racing	Rafts with either two (R2), 4 (R4) or 6 (R6) competitors per raft completing a series of three events. Scores from each event are taken to identify the overall winner. These events are (1) a slalom race, gates are negotiated down a course in the fastest possible time; (2) downriver race; an endurance race down a stretch of river; and (3) head-to-head sprit, two rafts competing head-to-head over a short stretch of river

With the development of man-made courses and easier access to rivers worldwide, participation has increased. White-water paddlesport participation statistics are not available worldwide; however, it is estimated that 1.9 million individuals participated in white-water kayaking in the USA during 2012 [3]. In addition to white-water kayaking, commercial white-water rafting is a popular recreational activity worldwide, which offers the opportunity for participants to experience white-water with limited previous experience. Approximately 3.7 million Americans participated in white-water rafting in 2012 [3].

Modern paddlesports involve a range of competitive and recreational activities. There are 11 competitive disciplines, involving a wide range of different craft, equipment and water conditions, each overseen by the International Canoe Federation (ICF) and International Rafting Federation (IRF). The white-water disciplines can

Fig. 23.1 A kayaker, recreationally negotiating quite extreme and very challenging white-water (Image © courtesy of Dale Mears)

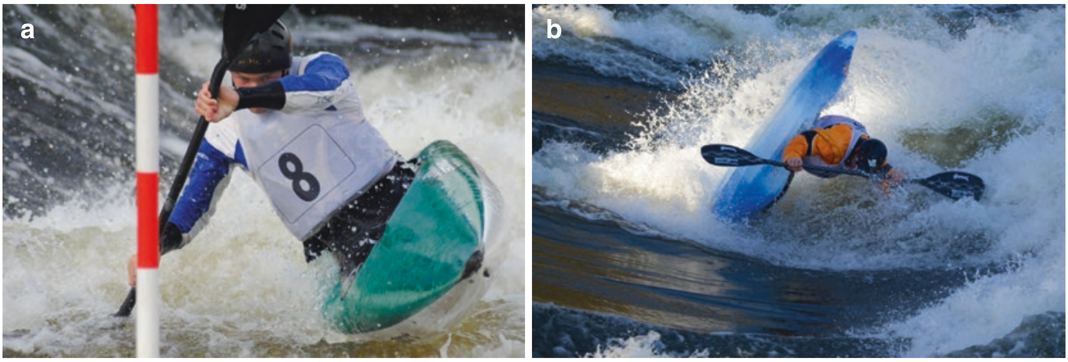

Fig. 23.2 (**a**, **b**). Examples of competitive disciplines in white-water paddling. Image (**a**) is a kayak slalom paddler negotiating gates along the river. Image (**b**) is a freestyle kayaker performing acrobatic manoeuvres to score points (Images © courtesy of Dale Mears)

be seen in Table 23.2. Canoe slalom, wild-water canoeing and canoe freestyle are the primary white-water disciplines. Other white-water disciplines include rafting and surf/waveski. Some canoe marathon and ocean racing (surfski) events involve white-water depending on the course or weather conditions; however, this is not the norm. White-water paddlesports are often performed for recreation and include activities such as playboating, white-water touring and river running. Some paddlers seek out the most extreme and challenging white-water by descending grade V and VI rapids. This can involve running waterfalls, first descents or seldom-navigated rivers (Fig. 23.1).

23.1.3 Craft, Equipment and Safety Recommendations

White-water can be negotiated in various craft of different shapes and sizes, depending on the purpose of the experience. Longer, narrow boats are designed for speed, particularly those with 'V'-shaped hulls such as wild-water racers. Shorter crafts are more manoeuvrable and are appropriate when sudden changes in direction are desirable. The construction of paddlesport craft has evolved over time meaning that they are generally lighter and more robust. The evolution of robust recreational boats has facilitated

Fig. 23.3 Examples of commercial white-water rafting. Image (a) is a raft negotiating a grade IV rapid, with all the clients safely inside the raft (Image © courtesy of Jon Best)

the descent of waterfalls and previously 'unrunnable' rivers. Higher-grade white-water (III+) requires the craft to be either decked (watertight) or packed with air bags (inflatable bags that limit water entering the craft). However, inflatable and sit-on-top crafts which are increasing in popularity with novices on lower-grade rivers (I–II) and modern white-water rafts (Fig. 23.3) are self-bailing, meaning they drain and therefore do not flood with water.

Choice of paddle design is dependent on paddling discipline, the physique and ability of the paddler. Longer paddles, with a greater blade area, are generally used where linear speed is important. In addition, greater feather angle (45–85°) and winged blades ('spoon' shaped with a distinct upper lip) are popular amongst those who race in kayaks. Some kayak paddlers use cranked shafts, which is suggested to improve performance and reduce injury risk, but this is not supported by empirical evidence. White-water rafters require longer paddles to reach the water. For higher-volume rivers, ores can be attached (typically with a metal frame) so the raft can be propelled by oars as well as paddles.

Preparation is critical. Appropriate equipment can mitigate the risk of some injury events or help manage situations that are already occurring (e.g. a capsize). It is recommended that the following items are essential for any paddling session:

- *Helmet* – That is approved for use on white-water (e.g. CE EN 1985). Face guards are also advised on steeper, shallow rivers.
- *Personal floatation devices (PFDs)* – That provide a minimum of 60 N of buoyancy (more is recommended for higher-grade and volume rivers) and should be white-water approved.
- *Clothing with the appropriate thermal properties* – Mountain rivers are often cold (<5 °C) despite the temperature of the air. Clothing to keep warm/cool enough for the duration of the expedition is important. Wetsuits are popular with commercial white-water rafting providers because of the thermal properties, additional buoyancy and extra protection from impact injuries whilst 'swimming'.
- *Throw bag* – A bag of rope used to rescue swimmers. It can also be used to set up mechanical advantage systems.

Table 23.3 A summary of white-water safety information [2, 4]

Know your limits
Be a competent swimmer in open water
Have and use (where necessary) all the essential equipment: PFD or buoyancy aid, helmet, rescue equipment, etc.
Know the river and weather conditions
Have the appropriate clothing for the conditions
Paddle in a group
Do not paddle under the influence of drugs or alcohol
Know how to deal with a capsize event

- *River knife* – A necessity, when carrying a rope, in case the rope becomes tangled and needs to be released quickly.
- *First-aid kit*

Extensive information and training are available from many paddlesport organisations (clubs, federations, etc.). A summary of important safety information can be seen in Table 23.3.

23.1.3.1 White-Water Injuries and Ill Health

- Accidents and injuries in white-water paddlesports are relatively rare, but due to the unpredictable environmental conditions associated with white-water sports, the consequences of accidents can be severe [5]. Injuries whilst submerged (including drowning, near drowning and impact traumas) are life threatening and account for approximately a third of white-water injuries [6]. Fortunately, fatal injuries are relatively rare. Drowning and submersion are the most common causes of fatal injuries [6, 7] and most often occur:
- In inexperienced paddlers attempting rivers beyond their skill level
- In adverse weather conditions
- In high-water conditions
- When appropriate safety equipments are not worn or used

Risk of fatalities increase as a result of entrapments, either foot or full body on strainers [8], blunt head trauma and symptoms of hypothermia (disorientation, loss of consciousness) linked to sudden immersion in cold water. This can further cause hyperventilation, bronchospasm and even cardiac arrest [9]. As the formal cause of death is not always available, it is unclear whether drowning is primary or secondary to another injury. This is particularly the case when fatal injuries are reported in the media.

Fatal injuries are extremely rare with a rate of 0.16–0.27 per 100,000 participants per annum for WW rafters [10] and a rate of 2.1 per 100,000 white white-water kayakers [11]. For all white-water paddlers, an injury rate of 0.86 per 100,000 user days has been observed [11] which is similar to trekking [12].

Survey data has estimated that per 1000 paddler days, 4.5 injuries occur amongst recreational canoeist and kayakers [13] and 5.2 injuries amongst competitive slalom canoeists and kayakers [14]. When compared to other outdoor adventure sports, the incidence of injury is similar to alpine skiing but higher than cross-country skiing or windsurfing [15, 16]. The injury incidence in commercial white-water rafters which required medical attention was estimated as 26.3 per 100,000 participants [17]. A much lower injury incidence of 1.04–1.81 per 100,000 participants required hospitalisation [10]. As with most sports, the incidence of white-water injuries rises with increased exposure [13] and is much higher during competition than training (ten times higher in competitive slalom paddlers [14]).

White-water injuries and ill health can be categorised as acute trauma injuries, chronic overuse injuries and environmental injuries and ill health. Most research has involved self-report data, as opposed to clinical or medical diagnoses. What literature there is has identified the upper body as most susceptible to injury for canoeists and kayakers. This is unsurprising as it is a predominantly an upper body sport. White-water rafters, who are in close proximity with others and are more likely to fall in the river, when compared to canoeists and kayakers, have a different pattern of injury. The facial region (33 %) and lower limbs, specifically the knees (15 %), are more at risk than the shoulders (6 %) [17].

Survey data has suggested that 42–51 % of all canoe/kayak injuries require medical attention

[13, 18]. The shoulder is the most common site for severe injury in canoe/kayak paddlers. One study reported 14 % of all injuries were shoulder dislocations [18]; another survey reported that 15 % of international-level elite paddlers had experienced at least one shoulder dislocation [14]. In addition, more than half of elite slalom paddlers have reported a history of shoulder injuries [19].

Injuries sustained by white-water paddlers occur:

1. In boat – Accounting for 51 % of injuries amongst rafters [17] and 87 % of injuries amongst kayakers [18]
2. Swimming – Accounting for 40 % of injuries amongst rafters [17] and 8 % of injuries amongst kayakers [18]
3. On land – Accounting for 5–9 % of injuries [17, 18]

23.2 Acute Traumas

Acute traumatic injuries are the primary form of reported injuries, accounting for 58–62 % of all canoe/kayak injuries [13, 14]. Of acute injuries reported, the most common amongst canoe/kayak paddlers included sprain/strain (26 % of acute injuries), lacerations (17 %) and contusions (17 %) [13], and amongst competitive canoe/kayak paddlers, sprains (35 %) and tendonitis (20 %) were common [14]. A survey suggested that commercial white-water rafters experience similar acute injuries to canoe/kayak paddlers: lacerations (33 %), strains and sprains (23 %), fractures (23 %) and contusions/bruises (10 %) [17].

23.2.1 In Boat

In-boat injuries sustained by canoe/kayak paddlers tend to be in the upper body, as this is the most exposed and therefore vulnerable part of the body [8, 13, 14, 18]. Sudden internal or external forces on the body may overload a muscle group or joint resulting in muscle strain or joint sprain injuries, for example, forceful paddle strokes to make an eddy or an attempt to stay upright with a powerful support stroke. The shoulder and lower back are susceptible to strain/sprain injuries. Lacerations, contusions, abrasions and fractures to any exposed region of the body are common as a result of collisions with rocks [13]. This could be whilst upright or upside down prior to completing an Eskimo roll (a method of righting oneself following being upturned on a river) [8]. Collision injuries are the most common form of injury amongst rafters [17]. This is from colliding with other rafters (those in the middle of the raft are most at risk), especially if they are holding their paddle incorrectly, allowing the loose end to swing into others on the raft. Consequently, facial lacerations, contusions, abrasions and dental damage are common rafting injuries [17]. Lower extremity injuries can also occur whilst in boat. For example, rafters can entrap a foot in the gutter of the raft whilst being thrown out of their seat resulting in knee and ankle damage [8]. Paddling a kayak head-on into an obstacle causes a sudden deceleration that can sprain the ankles [8].

As previously mentioned, shoulder dislocations are not uncommon, e.g. 15 % of respondents of one survey had reported having at least one [14]. This is a severe injury, which typically requires several weeks of immobilisation and a prolonged absence from paddling. Strenuous high brace supports to avoid capsizing have been associated with the anterior displacement of the humeral head, resulting in either a dislocation or subluxation. Poor high brace technique is widely considered to make the shoulder vulnerable to dislocation (Fig. 23.4). A combination of shoulder abduction with external rotation and extension can lever the humeral head out of the glenoid fossa. Extension of the elbow also increases the force transmitted along the arm, increasing the risk of wrenching the humeral head out of the glenoid fossa. Good practice for a high brace involves reducing the abduction and external rotation of the shoulder, the elbow lower and further forwards than the shoulder, the hand in front of the elbow and the elbow flexed. It has been suggested that female paddlers, who generally have less muscle mass to help stabilise the shoulder,

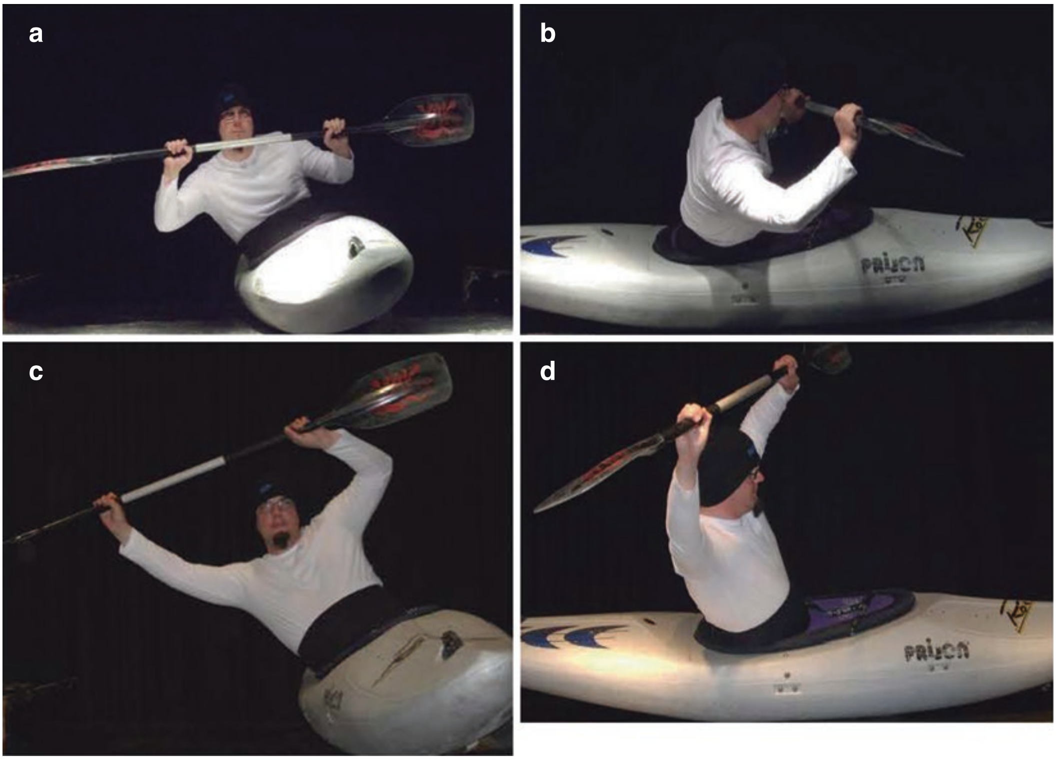

Fig. 23.4 Good high brace technique (**a**, **b**) and poor high brace technique (**c**, **d**) with regard to the risk of shoulder dislocation

are at greater risk of shoulder dislocations [7]; however, there is little empirical evidence to support this claim.

Other extreme injuries may occur on grade V and grade VI descents and waterfall jumping. Although there are no scientific reports of these injuries, there are numerous anecdotal reports and online databases (e.g. American Whitewater) which provide some insight into such incidents. For kayak paddlers, descending waterfalls involves an inherent risk of spinal damage, including vertebral compression fractures, from the high-impact forces experienced on landing, especially if the boat lands flat [20]. Such injuries may cause paralysis. Other potential impact injuries include long bone and pelvic fractures, abdominal/chest trauma and head injuries. It is therefore important to have the relevant rescue and medical support teams available on site when attempting waterfall descents.

23.2.2 Swimming

Turbulent water can cause craft to be unstable, resulting in a capsize and the paddler ‘falling out’ of their craft. In the event of swimming, it is important for the paddler to stay close to their craft as this provides an excellent flotation aid. In the event of ‘falling out’ of a raft, holding on to the perimeter rope whilst twisting and falling may cause contusions and abrasions on the hands, specifically around the fingers and fingernails. If the water is particularly powerful, holding on to the raft may be damaging as it puts a lot of pressure on the wrist, elbow and shoulder joints. In this situation, there is a risk of sprains.

Swimming in turbulent water is a highly unpredictable situation, where the swimmer has limited control and consequently there is a significant risk of impact with rocks and other obstacles. Frequent injuries to the lower extremities include lacerations, contusions, abrasions and fractures [10, 13, 17]. Although the lower extremities are at higher risk of injury, other regions of the body are also at risk [8]. It is recommended that swimmers adopt a defensive swimming position to avoid submerged obstacles. If defensive swimming is not adopted, the risk of entrapment will increase. Entrapments are rare but serious and tend to happen in shallower rivers (waist deep) or in flooded rivers where other obstacles become submerged (e.g. trees, fences) creating additional hazards. The most common form is a foot entrapment; this is where the foot or ankle is trapped by an obstacle such as a tree root or between two rocks. The force of the water can make it very difficult to dislodge the entrapped body part and a rescue may be required. Even minor entrapments typically causing abrasions and contusions with sprains and fractures are also possible. In extreme cases where the force of the water is great, drowning is a likely outcome. Entrapments are very serious and the victim needs to be rescued as quickly as possible from the situation. The severity of the accident will increase with time taken to rescue the individual.

23.2.3 On Land

Trekking to and from a river, portaging around rapids or performing a land-based rescue all increase the risk of ankle sprains, foot injuries and falls amongst paddlers. The uneven surface of a river bank is often slippery and unstable making these situations potentially hazardous, particularly when carrying a boat and/or other equipment. Robust footwear with good grip is highly recommended but not typically worn by paddlers.

During rescues, using a throw line or rope, creating a 90° kink in the rope will reduce the chance of the rope slipping through the hand (Fig. 23.5) and reducing the risk of rope burn. Gently moving downstream with the ‘swimmer’ on the line will also reduce the pressure on the rope and therefore the risk of abrasions from the rope for both the rescuer and ‘swimmer’.

Fig. 23.5 Creating kinks in the rope reduces the risk of rope burn from the rope slipping through the hands

When setting up mechanical advantage equipment for a rescue, such as a pinned boat, it is essential to check that all screwgate karabiners are fastened and closed correctly before pulling on the rope. Keep the head down, whilst wearing a helmet, and face away from the direction of any equipment if possible. This will protect exposed areas of the body from debris should any of the equipment fail under the strain. Specific training for white-water safety and rescue is required before using mechanical advantage systems.

23.3 Chronic Overuse Injuries of Paddlesports

Although chronic overuse injuries have not been reported as frequently as acute trauma, they are still relatively common, accounting for 25–40 % of all injuries sustained by canoe/kayak paddlers [13, 18]. Back pain lasting longer than a week was reported by 20 % of raft guides in one survey [21]; however, due to the infrequency of participation for commercial white-water rafters, chronic injuries are uncommon. Stress from white-water conditions can exacerbate overuse injuries; therefore, sufficient rest and recovery is important [18].

23.3.1 Hand, Wrist, Forearm and Elbow

Unsurprisingly, the hands, wrists, forearms and elbows are a region at risk of injury as power is regularly channelled through these muscles and joints. Paddling involves repetitive extension and flexion of the wrist, whilst gripping the paddle intensely. Paddle strokes sometimes require stabilisation of the paddle in unpredictable water conditions. No research has been conducted to identify which paddlesport is more at risk of chronic injuries in the wrists and forearms.

Tenosynovitis of the wrist extensor tendons is a common overuse injury amongst kayak paddlers, which predominantly occurs in the control hand [22]. Tenosynovitis is characterised by inflammation of the sheath lining surrounding the tendons within the dorsal aspect of the wrist/forearm. It has been reported to be the most common injury in Olympic canoe/kayak paddlers [23] and is also common amongst marathon kayakers [22]. The incidence of tenosynovitis has been associated with the surface water and wind conditions, rather than the feather angle of the paddle [22]. Carpal tunnel syndrome, median nerve entrapment (from flexor tendon hypertrophy) and tenosynovitis of the wrist flexor tendons (from excessive gripping of the paddle shaft) can also occur in canoe/kayak paddlers. Another condition reported in the literature is De Quervain syndrome, which is a tenosynovitis associated with the abductor pollicis longus and extensor pollicis.

Canoe paddlers who frequently use the ‘J’ stroke to maintain their course are at risk of flexor ‘tendonitis’ [24]. Extensive use of the ‘J’ stroke is thought to cause injury to the elbow, specifically medial epicondylitis although this particular type of overuse injury is quite rare [23].

Intense paddling in any type of craft can result in forearm exertional compartment syndrome. Symptoms include pain, tightness and hard muscle compartments, typically in the wrist flexors and abductors, during or following intense exercise. Although unpleasant, this is self-limiting with a few minutes of rest. This condition can recur persistently amongst competitive paddlers which can impact on performance. Conservative treatment involves technique analysis to identify the primary cause of muscular overload in the forearm and strengthening of these muscles with specific exercises. However, persistent cases can be unresponsive to conservative treatment and surgical fasciotomy that reduces the build-up of intramuscular pressure during exercise [25].

23.3.2 Shoulder

The combination of environmental, intrinsic and extrinsic factors can contribute to rotator cuff tendinopathy [26, 27]. Persistent abduction and internal rotation of the top hand for canoeists, and possibly rafters, can cause impingement of the supraspinatus tendon and subacromial bursa against the acromion and coracoacromial ligament [24]. This injury is less frequently reported by kayak paddlers as the paddle shaft is not usually placed to be in such a vertical position, thus requiring less abduction of the shoulder. It is believed that impingement experienced by these individuals was a secondary injury. This is caused by the growth of acromioclavicular bony spurs impinging the supraspinatus, rather than primary impingement due to restricted subacromial space. Surrounding muscles are believed to also be at risk of strain (e.g. biceps brachii and pectoral muscles); however, detailed investigations are lacking.

23.3.3 Back

In spending prolonged periods of time in a boat involving repetitive, heavy rotational and shear loads, kayak paddlers are susceptible to paraspinal fatigue and lumbosacral strain. From a sample of competitive kayak paddlers (predominantly flatwater), 23 % reported experiencing pain, limited movement or numbness in their back [28]. The incidence of back problems amongst elite competitors has been reported between 20 and 52 % [19, 28]. Back problems can be serious if untreated; of a group of 63 elite competitors, 18 % were diagnosed with spondylolysis, 16 % with myofascial pain syndrome and 13 % with spondylosis deformans [28]. As the sample was predominantly flatwater paddlers, the extent of the risk to white-water paddlers is unknown. However, high volumes of intense training or recreational paddling may contribute to severe back problems, especially if they go unidentified and untreated. Increased sagittal plane spinal curvature [29] and shortened hamstrings [30] are believed to contribute to back injuries amongst sport participants, including canoe and kayak paddlers [31].

A high proportion (77 %) of raft guides reported experiencing back pain at some point during their career, with 21 % experiencing pain enduring longer than a week [21]. This was reported to be similar to the general population (5–30 %), although only 7 % reported taking time off work because of the pain, compared to 9–29 % in other industries. Back pain was associated with manual handling tasks, such as loading and unloading equipment [21]. Sudden twisting movements required to lift and throw the raft onto the stack are believed to contribute to such pain; however, observation data would be beneficial to support this survey data and to draw more robust conclusions.

In addition to manual handling techniques, on-river practices may contribute to the back pain experienced by raft guides and canoeists. Raft guides and canoeists may prefer to paddle on a single side, their dominant side (unilateral guiding) which leads to the overdevelopment of certain muscle groups. If these muscle groups remain unbalanced, over a prolonged period of time, there is a risk of scoliosis.

23.3.4 Pelvic and Lower Limb

Spending prolonged periods of time in either a kayak or canoe can potentially have long-term effects. The seating position of a kayak, combined with rotating on a hard seat, is suspected to be associated with ischial tuberosity bursitis and hamstring tendonitis. Olympic-level paddlers and marathon paddlers, who spend prolonged periods in their boats, have also reported experiencing sciatica [23, 32]. Altering the height of the seat does not appear to reduce the incidence of sciatica [32]; however, benefits have been identified from ergonomic changes to the seat design and shape [23].

Raft guides may incur damage to their knees as a result of their foot positioning in the raft. If the guide locks their foot in a static position (e.g. under the thwart or in the gutter of the raft) whilst performing turning strokes (e.g. pry or sweep stroke), then rotational forces may be transferred through the knee, causing damage to the meniscus. Although information about such risks are presented in training, there is no scientific or medical evidence published in the literature to confirm or disprove this risk.

23.4 Environmental Illnesses

A third of injuries and illnesses reported in competitive canoe and kayak paddlers were attributed to environmental conditions [14]. Skin complaints and gastrointestinal illness (related to exposure to river water) and cold and heat injuries (from extreme temperatures) are examples of medical complaints experienced by paddlers.

Whilst participating in white-water activities, individuals may have prolonged contact with water or moist clothing, making them susceptible to mild skin infections. Folliculitis can occur where tight equipment, such as river jackets or drysuits, cause mild skin irritation from rubbing. Areas of the skin which are frequently moist and abraded (including the groin and axillae) are vulnerable to fungal infections. Most cases do not require specific treatment other than regular cleaning and careful drying. However, regular paddlers may be predisposed to an increased rate of wound infections because of repeated immersion in water. Cross contamination can also occur when paddlers are clustered together, for example, outbreaks of skin infections (*Staphylococcus aureus*) have been observed in raft guides [33].

Exposing the ear canal to contaminated water can cause infection or canal irritation. Otitis media and otitis externa have been reported to affect 5 % of paddlers in one study [34]. Repeat exposure to cold water can cause external auditory canal exostoses (EACE), also known as surfer's ear [35]. This is where the surface of the external auditory canal becomes elevated, constricting the passage and thus impairing hearing. Submersion in cold water, such as rivers, through capsizing has been reported to contribute significantly to the development of EACE [35]. The severity of this condition has been associated with the frequency of exposure to white-water rivers over time. Over 90 % of WW kayakers, who had paddled for 10 years or more, showed symptoms of EACE. Severe cases of EACE, defined as greater than two thirds of the external canal being obstructed, were only observed in those kayakers who have paddled for 10 years or more. This was specifically associated with water sports as opposed to outdoor sports in general as significantly more symptoms of EACE were observed in kayakers (69.5 %) when compared to a group of rock climbers (1.7 %). Although EACE has only been examined in kayakers, there is a risk to any participant of white-water activities who is frequently submersed in cold water. Avoiding submersion in cold water and protecting the ear canal through the use of ear plugs have been suggested to help reduce the risk of developing this condition.

Hand blisters, caused by abrasion from gripping the paddle shaft, are the most common injury amongst white-water paddlers afflicting 65 % [15] and 94 % [13] of respondents in two surveys. The base of the thumb is the most common site. Individuals who have not developed calluses, primarily novices, or are using new paddles are susceptible to incurring blisters.

23.4.1 Infections and Disease

Ingestion of contaminants in the water such as *E. coli* and other bacteria [36] and viruses such as the Norwalk virus [37] can contribute to gastrointestinal illness. Such illnesses are fairly common amongst white-water paddlers due to the high exposure to river water combined with exercise-induced lowered immunity. Surveys of competition paddlers have found 13 % of slalom paddlers [14] and 14 % of Dusi marathon competitors [36] were suffering with diarrhoea. Giardiasis infection, a parasitic infection of the digestive system, has been reported amongst white-water paddlesport participants [6, 17]. Although the symptoms are unpleasant (e.g. diarrhoea and increased flatulence), they do not usually pose a serious threat to health. If symptoms are persistent, this infection should be treated with antibiotics, following a stool sample to confirm diagnosis and sensitivity.

Leptospirosis (Weil's disease) is a bacterial infection caused by exposure to *Leptospira interrogans*. Common exposure to this is through direct or indirect contact with animal urine, specifically rodents such as rats. Mild symptoms, including flu-like symptoms and fever, are quite common and are less serious. Occasionally, the infection can progress to become Weil's disease presenting as jaundice and haemorrhagic illness that can quickly lead to multi-organ failure. In the UK, there are approximately 50 cases annually of which an average of three are fatal. A blood test is the only reliable diagnostic tool. Prompt treatment with antibiotics (e.g. oral doxycycline) is important to prevent deterioration.

Upper respiratory tract infections are commonly reported in all elite-level sports, white-water kayaking being no exception. One survey identified that 34 % of elite white-water kayakers reported upper respiratory infection and 13 % sinusitis [14].

Exposure to river water following heavy rainfall may increase the risk of infections and ill health as contaminants can get washed into the river [38, 39]. As some rivers are more popular or best negotiated following heavy rainfall, this may increase exposure to contaminants and therefore increase the risk of ill health. Experienced white-water paddlers were identified at a lower risk of contracting an illness from the water; this was believed to be related to a developed immunity over time [39]. However, experienced paddlers are less likely to capsize, and therefore, their exposure to the water is limited in comparison to novice paddlers who capsize more frequently.

23.4.2 Cold/Heat Illness

As with any outdoor activity, there is the risk of hypothermia if clothing with insufficient thermal properties is worn in cold weather. Symptoms include shivering (shivering stops when the hypothermia becomes severe) and numbness of extremities followed by apathy, confusion, lethargy and slurred speech. If symptoms are recognised as being present, then it is important to get the paddler off the water, dried and warm their core. Extreme heat is just as dangerous as extreme cold. The symptoms of heat stroke (including confusion, headache, thirst, nausea, rapid shallow breathing and muscle cramps) need to be recognised. The paddler should be removed from the water and rested in a cool location; appropriate layers are to be removed, rehydrated and possibly externally cooled (e.g. cold drinks, ice packs, etc.). It is important to anticipate and to be prepared for the conditions, carrying equipment including blankets, drinks (warm and cold), survival bag, etc. For both conditions, recognising the need for hospital treatment is vital.

It is important to protect against ultraviolet radiation (UVR), which can be reflected by sand and water up to 17 % and 100 %, respectively. In the short term, this can increase the chance of eye damage and sunburn to the exposed skin, and in the long run, there is the risk of skin cancer [8]. This is particularly the case when paddling or rafting on mountainous rivers, as UVR increases with altitude [40].

23.5 Prevention

With the exception of white-water centres, white-water paddlesports take place in generally remote locations, with limited first aid or emergency assistance/accessibility available. The prevention of accidents is therefore better than treatment, especially as the immediate management of accidents and injuries whilst on white-water is problematic. Individuals should know their limitations and have sufficient skills and physical abilities for the conditions. At minimum, they should seek advice or paddle with experts with experience of the particular white-water being negotiated, if it is unfamiliar to the individual. A qualified first aider should be present in the group, and necessary equipment, including complete and in date first-aid kit, drinks, food, spare clothing and spare paddle.

23.5.1 White-Water Accidents and Injury Reduction

Injury prevention initiatives aim to raise the resilience of the paddler and/or reduce the external stress on the body. Equipment should be well maintained and its functionality checked prior to use. In addition to appropriate equipment, education of paddlers is vital. This applies to all injuries and health risks, whether it be awareness of illnesses such as Weil's disease or specific local dangers such as low-head weirs/dams. Weir hazards are responsible for a number of fatalities and near drownings where paddlers have attempted apparently innocuous weirs/dam only to get caught in a recycling rapid (stopper wave) that pulls them under [41]. Increasing the number and visibility of warning notices may prevent further accidents where these hazards reside.

A high proportion of rafting injuries occur whilst in the raft, with a third of these occurring to the facial region [17]. It has been suggested that limiting the number of individuals in the rafts and providing rafters with face guards may reduce the risk of impact injuries (due to rafters colliding with each or equipment). However, reduced numbers in a raft may affect the dynamics of a raft, for example, rafts with reduced propulsion and weight may be more likely to be retained by a stopper wave. Face guards can reduce visibility and may increase the risk of entrapment whilst submerged and therefore may be a greater risk to health [17].

Prior to starting a paddling trip, event or competition, the paddler must have the appropriate ability and physical capability to complete the required task. For example, the risk of tenosynovitis in long-distance kayakers was reduced by extensive training (>100 km per week) in the weeks prior to the event [22]. Furthermore, strengthening synergist and joint stabilising tissues through strength and conditioning are recommended for paddlers at all levels and should specifically include exercises for the scapular, glenohumeral and core stabilisers. Specific strength training can increase the resilience of body regions at high risk of injury [42]. In addition to specific strength training, correct paddling technique is essential in maintaining stability in the shoulder region [43]. Basic technique of strokes should be practised to a good standard before pursuing challenging water.

Competitive paddlers should undergo regular health screening including both clinical (health) and kinesiological (musculoskeletal) investigations. Pre-existing medical conditions and issues with muscle and biomechanical imbalances should be identified and addressed. This will allow the opportunity to develop individualised prehabilitation programmes where necessary. Prehabilitation aims to reduce injury risk by correcting functional weaknesses, imbalances, poor posture or malalignment through specific conditioning exercises. This may involve reduced paddling and other physical activities until the weaknesses are addressed. Prehabilitation has been suggested, anecdotally, to reduce the risk of shoulder dislocations in paddlers; however, there is little or no empirical evidence to support this at this time. Despite the lack of published studies, prehabilitation is a widely accepted method of risk mitigation [42]. Clearly, this level of support is often only available to elite-level competitors. Careful monitoring of training load throughout the season with a systematic progression of intensity and volume is important for prevention of overuse injuries.

Excessive tension from gripping the paddle and unnecessary wrist flexion or extension from poor paddling technique may contribute to forearm injury. Specific gym training can develop the forearm musculature which may reduce the risk or prevent such injuries. Altering the paddle setup, for example, cranked shafts and reduced angle of feather of kayak paddles used, may prevent an individual experiencing problems. One survey found that 13 % of respondents ($n = 41$) reduced the feather angle of their kayak paddle to alleviate a wrist complaint, of these 73 % benefited from this alteration and reported a reduction in their wrist complaint [13].

Manual handling, including the loading and unloading of equipment on to/off of trailers, etc., has been associated with lower back pain. Reducing the load of manual handling, either using more individuals or mechanical systems (e.g. a hoist), may reduce the risk of lower back injury [21].

23.5.2 Illness Reduction

Good hygiene practices, particularly before consuming food and drink, should be practised after participating in white-water paddlesports. If in remote locations, good hygiene can still be practised with the use of portable soaps/gels, etc. This will reduce the risk of gastrointestinal complaints. In a competitive or work environment, isolation of contagious cases helps reduce the risk of spreading the illness to others. Probiotic use has been studied in the general population. Reviews have found they reduce duration of diarrhoeal illness and may prevent occurrence [44]. The use of ear plugs may reduce the amount of contaminated water being exposed to the ear canal and thus may prevent otitis media and otitis externa. The use of ear plugs may also protect against long-term problems such as external auditory canal exostoses. The use of an appropriate factor, water-resistant sun block and appropriate sun glasses will protect the skin and retina from UVR. The reapplication of sun block is vital if spending prolonged periods of time in the sun.

23.6 Treatment and Rehabilitation

The delivery of treatment may not always be possible following an accident on a river in a remote location. It is therefore vital that at least one member of the group is first-aid trained in order to manage any situation that may arise. In order to prevent the accident escalating, the victim should be relocated to a safe environment, i.e. off the water where possible. Once in a safe location, appropriate first-aid treatment can be administered. For more severe injuries, such as dislocations and fractures, medical attention is required. The urgency of this treatment is dictated by the condition of the patient. Once medical attention has been sought, standard principals of treatment for the injury should be applied. Examples of common treatments can be seen in Table 23.4.

It is important to fully recover from any injury or illness before attempting to paddle again. Recurrence and exacerbation are potential consequences of returning to normal activity too soon. It is therefore important to fully complete recommended rehabilitation programmes. Following musculoskeletal damage, the primary goal of early-phase rehabilitation is to achieve a full range of movement. This can include gentle flexibility and muscle-strengthening exercises that will help maintain movement and reduce the chance of adhesions and stiffness in joints. With

Table 23.4 Common examples of treatments for injuries and illnesses

Injury/illness	Treatment
Abrasions and lacerations	Wounds should be cleansed and dressed. Medical attention may be needed; if fluid irrigation, stitches and antibiotics are required
Fractures	Standard principles of fracture treatment should be applied. Urgent treatment is required prehospital if any of the following are present: altered sensation, loss of pulse and skin tenting
Muscular strains	Apply the principles of RICE (rest, ice, compression and elevation). Pain relief medication can be taken if necessary. Paracetamol has similar effects to analgesics without the tissue-damaging side effects [45]
Dislocations	The dislocated joint should be supported, and analgesics are appropriate to help alleviate distress. The decision of whether reduction be completed in a prehospital or hospital setting should be made on a case-by-case basis. Attending hospital is required. Even after relocation, surgery may be necessary depending on the degree of tissue damage
Chronic shoulder injury	Rest and non-steroidal anti-inflammatory drugs (NSAIDs) should be used early in treatment. Ultrasound-guided injections are sometimes necessary and can facilitate physiotherapy. Surgery is a last resort if other treatments fail
Elbow, wrist and forearm tendinopathies	Applying the principles of RICE and using NSAIDs can be effective in the short term. Injections of local anaesthetic and corticosteroid can be effective [46]. Injections of autologous blood and platelet-rich plasma have a growing evidence base [47, 48] Surgery is now rare and only undertaken in extreme cases
Blisters	Should be kept clean. If infection is suspected, then lancing and draining the blister may be necessary. Taping may alleviate pain and allow paddling to continue
Skin infections	Antibiotic or antifungal cream should be applied directly to the site of infection. If widespread, oral medication is preferable
Gastrointestinal illness	Adequate oral hydration is essential. Once symptoms have subsided, the consumption of plain food such as the BRAT diet (bananas, rice, applesauce and toast) can aid recovery. Medical assistance is only necessary if symptoms persist

time, these exercises can increase with intensity, building up strength and functionality. For paddlers, activating core-stabilising muscles and scapular setting may benefit rehabilitation. Some injuries, particularly shoulder dislocations, carry a greater risk of recurrence, regardless of whether or not rehabilitation programmes are fully completed [49].

23.7 Summary

White-water paddlesports come with an inherent risk of injury and ill health due to the unpredictable environment of these activities. Injuries are relatively rare; however, in extreme cases they can be fatal. Canoeists and kayakers are at more risk of sustaining upper limb injuries, compared to injuries to facial and lower limb regions amongst rafters. Acute traumas, such as sprains, strains and lacerations, accounted for the majority of injuries sustained. Shoulder dislocations are also fairly common. The wrists, forearms and back are at most risk of chronic injuries with tendinopathy and sprain/strain being most common. Insufficient rest, poor technique and overgripping the paddle may contribute to such problems. Most injuries reported are treatable; however, treatment and rehabilitation must be fully completed to reduce the risk of injury recurrence or exacerbation. Where possible, it is better to avoid the risk of injury, through knowledge and the use of appropriate equipment, such as PFDs and helmets. Being prepared for the conditions of the trip/event is essential to reduce the risk of ill health.

References

1. British Canoe Union [BCU]. BCU terms of reference for coaches and leaders. 2012. Available at: http://www.canoe-england.org.uk/media/pdf/bcu/20terms/20of/20reference/20v4-0.pdf. Accessed Dec 2013.
2. Walbridge C, Singleton M. Safety code of American Whitewater. 2005. Available at: http://www.americanwhitewater.org/content/Wiki/safety:start. Accessed on Feb 2014.
3. Outdoor Foundation. The Active Outdoor Recreation Report. 2013. Available at: http://www.outdoorfoundation.org/research.recreation.html. Accessed Nov 2013.
4. Go Canoeing. Canoeing safety advice. 2014. Available at: http://www.gocanoeing.org.uk/go/index.cfm/hints-tips/safety-advice/. Accessed Feb 2014.
5. Caine DJ. The epidemiology of injury in adventure and extreme sports. Basel: Karger; 2012.
6. Kizer KW. Medical problems in whitewater sports. Clin Sports Med. 1987;6(3):663–8.
7. Burrell C, Burrell R. Injuries in whitewater paddling. Phys Sportsmed. 1982;10:119–24.
8. Weiss EA. Whitewater medicine. J Wilderness Med. 1991;2(3):245–52.
9. Baker S, Atha J. Canoeists' disorientation following cold immersion. Br J Sports Med. 1981;15(2):111–5.
10. O'Hare D, Chalmers D, Arnold NA, Williams F. Mortality and morbidity in white water rafting in New Zealand. Inj Control Saf Promot. 2002;9(3):193–8.
11. Wittmann L. Kayaking is safer than you might think (really!). Am Whitewater. 2000;100–1.
12. Shlim DR, Houston R. Helicopter rescues and deaths among trekkers in Nepal. JAMA. 1989;261(7):1017–9.
13. Schoen RG, Stano MJ. Year 2000 whitewater injury survey. Wilderness Environ Med. 2002;3(2):119–24.
14. Krupnick JE, Cox RD, Summers RL. Injuries sustained during competitive white-water paddling: a survey of athletes in the 1996 Olympic trials. Wilderness Environ Med. 1998;9(1):14–8.
15. Hartung H, Goebert D. Watersports injuries. Epidemiology of sports injuries. Champaign: Human Kinetics Publishers; 1996. p. 29–39.
16. Nathanson AT, Reinert SE. Windsurfing injuries: results of a paper-and Internet-based survey. Wilderness Environ Med. 1999;10(4):218–25.
17. Whisman SA, Hollenhorst SJ. Injuries in commercial whitewater rafting. Clin J Sport Med. 1999;9(1):18–23.
18. Fiore DC, Houston JD. Injuries in whitewater kayaking. Br J Sports Med. 2001;35(4):235–41.
19. Edwards A. Injuries in kayaking. Sports Health. 1993;11(1):8–11.
20. Baker S. The 'ultimate' waterfall. Canoeist. 1990:51.
21. Jackson DM, Verscheure SK. Back pain in whitewater rafting guides. Wilderness Environ Med. 2006;17(3):162–70.
22. du Toit P, Sole G, Bowerbank P, Noakes TD. Incidence and causes of tenosynovitis of the wrist extensors in long distance paddle canoeists. Br J Sports Med. 1999;33(2):105–9.
23. Walsh M. Preventing injury in competitive canoeists. Phys Sports Med. 1985;13(9):120–8.
24. Berglund B, McKenzie D. Injuries in canoeing and kayaking. Clinical practice of sports injury prevention and care. Oxford: Blackwell Scientific Publications; 1994. p. 633–40.
25. Wittstein J, Moorman CT, Levin LS. Endoscopic compartment release for chronic exertional compartment syndrome. J Surg Orthop Adv. 2008;17(2):119–21.
26. Bigliani LU, Levine WN. Current concepts review-subacromial impingement syndrome. J Bone Joint Surg. 1997;79(12):1854–68.
27. Lyons PM, Orwin JF. Rotator cuff tendinopathy and subacromial impingement syndrome. Med Sci Sports Exerc. 1998;30(4 Suppl):12–7.
28. Kameyama O, Shibano K, Kawakita H, Ogawa R, Kumamoto M. Medical check of competitive canoeists. J Ortho Sci. 1999;4(4):243–9.
29. Harrison DE, Colloca CJ, Harrison DD, Janik TJ, Haas JW, Keller TS. Anterior thoracic posture increases thoracolumbar disc loading. Eur Spine J. 2005;14(3):234–42.
30. Jones MA, Stratton G, Reilly T, Unnithan VB. Biological risk indicators for recurrent non-specific low back pain in adolescents. Br J Sports Med. 2005;39(3):137–40.
31. Lopez-Minarro PA, Rodríguez-García PL. Comparison of sagittal spinal curvatures and hamstring muscle extensibility among young elite paddlers and non-athletes. Int Sport Med J. 2010;11(2):301–12.
32. Carmont M, Baruch M, Burnett C, Cairns P, Harrison J. Injuries sustained during marathon kayak competition: the devizes to Westminster race. Br J Sports Med. 2004;38:650–3.
33. Decker MD, Lybarger JA, Vaughn WK, Hutcheson Jr RH, Schaffner W. An outbreak of staphylococcal skin infections among river rafting guides. Am J Epidemiol. 1986;124(6):969–76.
34. Powell C. Injuries and medical conditions among kayakers paddling in the sea environment. Wilderness Environ Med. 2009;20(4):327–34.
35. Cooper A, Tong R, Neil R, Owens D, Tomkinson A. External auditory canal exostoses in white water kayakers. Br J Sports Med. 2010;44(2):144–7.
36. Appleton CC, Bailey IW. Canoeists and waterborne diseases in South Africa. S Afr Med J. 1990;78(6):323–6.
37. Taylor M, Becker P, Van Rensburg EJ, Harris B, Bailey I, Grabow W. A serosurvey of water-borne

pathogens amongst canoeists in South Africa. Epidemiol Infect. 1995;115(02):299–307.

38. Boland M, Sayers G, Coleman T, Bergin C, Sheehan N, Creamer E, et al. A cluster of leptospirosis cases in canoeists following a competition on the River Liffey. Epidemiol Infect. 2004;132(2):195–200.
39. Lee JV, Dawson SR, Ward S, Surman SB, Neal KR. Bacteriophages are a better indicator of illness rates than bacteria amongst users of a white water course fed by a lowland river. Water Sci Technol. 1997;35(11–12):165–70.
40. Blumthaler M, Ambach W, Ellinger R. Increase in solar UV radiation with altitude. J Photochem Photobio. 1997;39(2):130–4.
41. American Whitewater Accident Database. 2014. Available at: http://www.americanwhitewater.org/content/Accident/view/. Accessed Feb 2014.
42. Pearce P. Prehabilitation: preparing young athletes for sports. Curr Sports Med Rep. 2006;5(3):155.
43. Wassinger CA, Myers JB, Sell TC, Oyama S, Rubenstein EN, Lephart SM. Scapulohumeral kinematic assessment of the forward kayak stroke in experienced whitewater kayakers. Sports Biomech. 2011;10(2):98–109.
44. Marteau P, Seksik P, Jian R. Probiotics and intestinal health effects: a clinical perspective. Br J Nutr. 2002;88(S1):51–7.
45. Paoloni JA, Orchard JW. The use of therapeutic medications for soft-tissue injuries in sports medicine. Med J. 2005;183(7):384.
46. Smidt N, van der Windt DA, Daniëlle AWM, Assendelft WJ, Devillé WL, Korthals-de Bos IB, Bouter LM. Corticosteroid injections, physiotherapy, or a wait-and-see policy for lateral epicondylitis: a randomised controlled trial. Lancet. 2002;359(9307):657–62.
47. Connell DA, Ali KE, Ahmad M, Lambert S, Corbett S, Curtis M. Ultrasound-guided autologous blood injection for tennis elbow. Skeletal Radiol. 2006;35(6):371–7.
48. Mishra A, Pavelko T. Treatment of chronic elbow tendinosis with buffered platelet-rich plasma. Am J Sports Med. 2006;34(11):1774–8.
49. Handoll H, Almaiyah M, Rangan A. Surgical versus non-surgical treatment for acute anterior shoulder dislocation. Cochrane Database Syst Rev. 2004;(1):CD004325.

Wakeboarding Medicine

24

Karsten Knobloch

24.1 Wakeboarding

Wakeboarding is a sport in which the athlete rides a board over the surface of water, pulled by a boat (Figs. 24.1 and 24.2) or installed overhead cable system. The rider jumps using the wake of the boat (hence the name wakeboarding) or ramps known as a *kickers*. Various tricks are performed, such as spins or flips, some with the help of a *slider*, a rail bar in which a rider approaches and rides along keeping his/her balance. Lakes, rivers or intercoastal waterways are generally the preferred bodies of water to practise this sport. Wakeboarding has become increasingly popular as a water sport over the past few years.

In Germany with its 82 million people, around 20,000 active wakeboarders are currently estimated, with 50 towing devices installed throughout the country. In the USA in 2014, the number of wakeboarding participants was estimated at 3,125,000 [1]. This chapter highlights both injuries (acute and overuse) and illnesses related to wakeboarding.

24.1.1 Equipment

Wakeboarding boats are equipped with a wakeboard tower, a thick-walled stainless steel or aluminium tubing structure, which places the *pull point* about 2 m above the water's surface. The athlete holds a triangular bar, measuring about 32 cm in length, with one or both hands—the rope is generally 20–25 m in length—and uses stiffer ropes than water skiing, because no-stretch tighter rope helps riders to get more air and to perform flips and spins. In cable wakeboarding, the athlete is pulled by a rapid cableway, using a towline measuring about 20 m in length, suspended at an angle of 10–70°, at a round running about 30 km/h. Boards are usually in fibreglass, with a core of foam, honeycomb or wood and resin. The shape and positioning of the fins may vary according to the rider's preference and types of tricks performed: finless boards are also used for particular tricks, especially in cable parks. Many boards are bidirectional, meaning they can be ridden in both directions: both the left and right foot can be adopted as the forefoot, allowing maximum freedom of action during the freestyle manoeuvres. Wakeboarding bindings are generally of the boot type, with adjustable straps, laces or buckles.

24.2 Acute Injuries

Serious acute injuries and even death can occur from wakeboarding participation [2]: fatalities have been reported as a consequence of subdural

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Figs. 24.1 and 24.2 Giorgia Gregorio wakeboarding (Photo courtesy of Ricardo Pinto)

haematoma following head trauma and from blunt cardiac trauma resulting in free wall rupture [2, 3]. Of the 122 injuries reported by 56 orthopaedic surgeons in a US-based analysis by Carson in 2004 [2], 21 % were represented by fractures, which mainly involved the thoracic or lumbar spine, femur, tibia, calcaneous and ribs. These injuries demonstrate that significant forces are being generated as the wakeboarder falls or simply lands hard on the water [2]: in addition to the speed of the boat or cable system, trajectory jumps and manoeuvres can generate significant deceleration and rotational forces. Almost all of the injuries occurred as a consequence of a direct or twisting impact with the water surface and not as a result of collision with obstacles such as docks, floating structures or watercrafts [2].

Baker et al., based on the data of the National Electronic Injury Surveillance System (NEISS) between 2000 and 2007, reported an estimated 18,967 wakeboarding-related injuries in the USA and an overall injury rate of 0.81 per 100,000 participants [4]. The authors also found that the injury rate more than doubled over this period. The age distribution of injuries showed a peak in late adolescence to early adulthood, then decreased with age, probably due to the popularity of this sport among youngsters. While a 33 % decrease in the number of the younger participants was found over the period of the study, the rate of injuries remained relatively stable: this led the authors to conclude that those who continue to practise wakeboarding were the participants who were the most reckless and who engaged in more extreme manoeuvres [4, 5]. The head and neck region was affected in 47.9 % of the cases: most of the injuries being represented by lacerations (51.3 %) and concussions (24.9 %) [4]. The hip and lower extremities were injured in 26.5 % of cases, and most of the injuries were strains and sprains (57.3 %) or fractures (21.3 %) [4]. Injuries to the shoulder/upper extremity and trunk accounted for 14.8 % and 10.6 % of injuries, respectively, and dislocations represented the most common diagnosis among upper extremity injuries (33.7 %) [4].

In a prospective study on cable wakeboarding involving 122 wakeboarders, Patzer et al. [6] found an overall injury rate of 32 injuries per 1000 h of practice: 12 per 1000 h of practice when considering only injuries requiring medical attention. Out of 277 reported injuries, 108 (39 %) were treated medically. The knee, shoulder and head were the most frequently injured regions, and minor injuries prevailed: 61 % of the injuries were mild, 15 % very severe, 14 % severe and 10 % medium-severe. Wakeboarding behind the boat is related to more serious injuries than cable wakeboarding, probably because of unpredictable disturbances such as the bow wave of the boat or natural obstacles [2, 5, 6]. Conversely in cable wakeboarding, the most common injury mechanism involves landing from a rotation jump over an artificial obstacle. Injury rate per participant correlates with increasing skills, injuries being mainly related to manoeuvres such as rotational jumps practised by more skilled athletes. Injury rate also increases with higher body weight and height, while material-related factors such as board length, bond type and manufacturer were not found to have any significant influence on injuries [6].

24.2.1 Head Injuries

The descriptive study by Hostetler et al. [5] involving 95 injured wakeboarding participants reported the head as being the most commonly affected body area, being involved in 29 % of injuries. Conversely, head injuries represented the smallest percentage of reported trauma for water skiers (4.3 %). Wakeboarders also sustained significantly more traumatic brain injuries (12.5 % of all injuries) than did water skiers (2.4 %). Lacerations were the most common diagnosis for wakeboarders (31.1 % of all injuries), and the majority (59.6 %) were to the face. Head injuries were mainly represented by midface contusions and lacerations also in cable wakeboarding and prevailed among beginners [2, 6]. A number of cases of eardrum rupture were reported in studies on wakeboarding injuries [2, 6], caused by the edge of the wakeboard catching the water and suddenly stopping, causing the athlete to fall, impacting the water headfirst. If one side of the head slaps into the water, the column of air contained within the external auditory ear canal is forced against the tympanic membrane and can cause it to rupture.

As early as in 2000, a Chinese case report discussed a 14-year-old male who sustained an unusual intracranial subdural haemorrhage while wakeboarding: the injury was attributed to the combination of both acceleration-deceleration and rotational forces [7]. Carson [2] also reported the case of a 21-year-old male wakeboarder, who sustained a subdural haematoma after hitting his head on the water while attempting a flip [2]. An acute ischemic stroke of the right basal ganglia and adjacent internal capsule, due to right internal carotid artery dissection, followed by one particular wakeboarding accident, is more recently reported by Fridley et al. [8]. The injury mechanism in that case probably involved high rotational deceleration of the body on the water and whiplash-type movements of the head and neck on impact.

24.2.2 Shoulder Injuries

Shoulder dislocations were the second most common injuries (14.7 %), following anterior cruciate ligament (ACL) tears, among 122 orthopaedic reported injuries examined by Carson [2]. In the series on cable wakeboarding by Patzer et al. [6], shoulder injuries were less frequent among expert athletes and were as follows: one shoulder dislocation as a consequence of a fall in the water, six long biceps tendon lesions, one tear of the biceps tendon anchor (SLAP lesion), three strains of the rotator cuff and one avulsion fracture of the greater tuberosity. Lim et al. [9] reported the case of a 32-year-old Chinese man suffering from rupture of both the sternal and clavicular attachments of the pectoralis major with muscle retraction of about 5 cm, as a consequence of a wakeboarding accident: he fell sharply on the water surface with his right shoulder in forced abduction and external rotation. This is a rare condition, with only about 200 cases reported in literature: it is frequently under- or misdiagnosed; therefore, it is important to be aware that it may occur as a consequence of wakeboarding falls. Two cases of closed proximal muscle rupture of the biceps brachii after wakeboarding traumas have also been described [10].

24.2.3 Wrist and Hand Injuries

In a case report, we highlighted a case of acute median nerve injury, following rope strangulation in a mechanical towing machine [11]. An intermediate male athlete with 12 months' wakeboarding experience was training on Germany's largest circular cable system, installed on a lake, at a speed of 40 km/h, when the system stopped suddenly due to an overlapping wire. The boarder dived in the lake, and his trunk and hand became trapped in the system's mechanism. He managed to free his body, but his wrist was still trapped when the system began operating once more without warning. He was pulled a quarter of the way around the lake at the previous speed of 40 km/h, suffering a strangulation of his wrist with immediate numbness of the area of the left hand supplied by the median nerve: he also sustained a laceration on the palmar aspect of the wrist measuring 0.5 × 5 cm. In the operating room, the dorsal compartment pressure of the forearm and the palmar compartment of the flexor carpi ulnaris muscle were both normal, measuring 16 and 19 mmHg, respectively. Seventy-two hours after the initial strangulation injury, the median nerve showed hyperaemia and moderate swelling and limited haematoma in the carpal tunnel more consistent with a median nerve contusion. The palmar branch of the median nerve was surrounded by a significant haematoma, which was evacuated. The ulnar nerve was inspected and found to be without any significant signs of injury or haematoma. On the first postoperative day, the patient regained the sensory function of the hand following 72 h of acute carpal tunnel syndrome with median nerve contusion, with remaining dysaesthesia of the thenar skin supplied by the palmar branch of the median nerve. On the fifth postoperative day, the patient was discharged home after an uneventful postoperative course.

Cable-associated injuries such as the aforementioned nerve contusions following wrist strangulation may not be uncommon in wakeboarding. In the UK [12], a 55-year-old man sustained a traumatic amputation of his dominant right hand while acting as an amateur wakeboarding instructor. The patient was in the water, assisting the launch of a novice wakeboarder, when the tow cable became wrapped around his wrist. The driver of the towing Jet Ski called out to ask if everyone was ready to start, as is standard practice in towing water sports, misheard the patient's reply of 'no' as 'go' and started to drive. The tow cable tightened around the patient's wrist, amputating the distal forearm at wrist level. The hand was lost to the sea, making re-plantation impossible, with a significant impact on the patient's daily life as a manual worker. The contaminated injury was treated according to military principles, with primary debridement and delay closure [13].

24.2.4 Knee Injuries

Thirty-one percent ($n = 38$) of the injuries reported by orthopaedic surgeons in the study by Carson [2] were represented by ACL tears. In the series on cable wakeboarding by Patzer et al. [6], most of the knee injuries were sprains ($n = 77$); however, three cases of ACL rupture and one case of dislocation, associated with both ACL and posterior cruciate ligament tears and accompanied by vascular damage, were also reported. Knee injuries most often occurred as a consequence of knee sprains, caused by the immersion of the board in the water when landing from jumps with feet fixed on the board by means of boot-type bindings, usually worn extremely tightly [6]. The lever action of the large surface area of the average board amplifies the rotational forces and may cause inner and outer belt stretches and meniscal and cruciate ligament lesions but may also lead to knee dislocation with combined injuries [6]. Starr and Sanders [14] in their descriptive epidemiology study on ACL injuries in wakeboarding, involving 123 amateur and professional athletes, found a prevalence of 42.3 % for this condition: one of the highest for any sport, although this value may be affected by the low response rate (7.22 %) and the possibility of selection bias, given that those with previous ACL injuries were probably more likely to answer the proposed survey.

Among the injured athletes, 14 (26.9 %) were classified as pro/advanced, 35 (67.3 %) as intermediate and three (5.8 %) as beginners. Interestingly, exposure time to wakeboarding was not a significant risk factor in the ACL injury group. The average hours per week spent wakeboarding by those with an ACL tear was 8.20 h, compared with 8.78 h per week in those who had not sustained the injury [14]. For ACL injuries specifically, the authors propose that, rather than rotational forces, the main mechanism involves axial compression acting on provocative position. Similarly to prior literature on alpine skiing, the presented data suggests that participants with higher skill levels have a lower ACL tear risk, even without sport-specific injury reduction training [14]. The authors also suggest that the actual skill level, increased fitness, coordination, and muscle balance of the athletes may play a preventative role.

24.2.5 Ankle and Foot Injuries

According to Hosteltler et al. [5], ankle and foot injuries represented 8.2 % ($n=393$) and 6.3 % ($n=307$) of wakeboarding injuries, respectively: reported wakeboarding ankle injuries in other series were sprains, ligament ruptures and fractures [2, 6]. Ankle injuries are less common in wakeboarding than in kitesurfing, probably because of the use of bindings: on the downside, these induce a higher potential of injury to the knee, due to the fixed connection between the lower leg and the board; on the upside, they stabilise the connection between the foot and the board, reducing the risk of injuries to the foot and ankle [15]. Specific injuries may occur in any case: fractures of the lateral process of the talus (LPT) have been reported [2, 16]. Rare in the general population, accounting for 1 % of ankle fractures, these injuries are approximately 15 times more common among snowboarders, earning them the name ‘snowboarder’s fracture’ [17]. The mechanism causing LPT fractures in wakeboarding and snowboarding is similar and involves a combination of axial loading, dorsiflexion and some form of ankle rotation [16]. Since about 40 % of LPT fractures are overlooked at the time of initial diagnosis, the possibility of this fracture should be taken into account when assessing patients suffering from wakeboarding injuries [16]: indeed the authors highlight the need for increased awareness of these fractures in wakeboarding.

24.3 Overuse Injuries

24.3.1 Patella Tendinopathy

In addition to traumatic acute injuries, such as those listed above, overuse injuries may also be associated with wakeboarding. A 16-year-old wakeboarder came to me in my personal practice, complaining of significant anterior knee pain, which worsened on landing. His typical regime consisted of wakeboarding five to seven times a week for 2–3 h each session. During the physical examination, he pointed to the patella apex as the maximum point of pain. A degree of knee effusion was also present. Using power Doppler ultrasound, I was able to demonstrate a significant neovascularisation at the Hoffa fat pad and in the proximal patella tendon, as seen in patellar tendinopathy (Fig. 24.3). There were no signs of a partial tendon rupture or intrasheath haematoma.

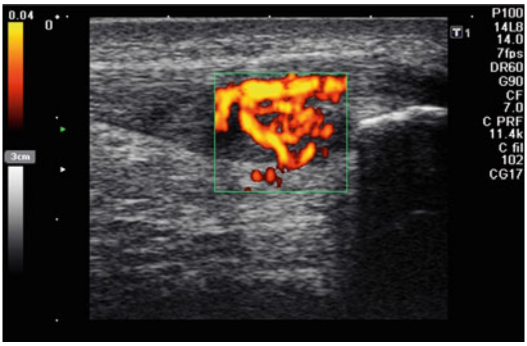

Fig. 24.3 Power Doppler ultrasound showing a patellar tendinopathy with a significant enlargement of the patellar tendon and substantial neovascularisation at the proximal patellar pole

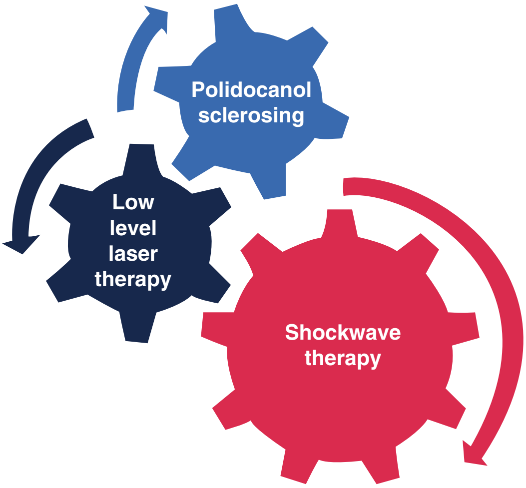

Fig. 24.4 Combined multimodal evidence-based tendon therapy in patellar tendinopathy in wakeboarding athletes with extracorporeal shockwave therapy (ESWT), low-level laser therapy (LLLT) and polidocanol sclerosing injection under power Doppler guidance

Using a combination of focused extracorporeal shockwave therapy (ESWT) with a Storz Ultra device, low-level laser therapy (irradia 904 nm), polidocanol sclerosing injections using power Doppler guidance and eccentric training (Fig. 24.4), the anterior knee pain was significantly reduced after two treatments and the young patient was advised to gradually increase wakeboarding training, beginning with one session per week.

24.3.2 Other Potential Tendinopathies

In addition to patellar tendinopathy, other tendinopathies may affect wakeboarding participants, due to overuse in training and/or competition: these include mainly knee-related tendinopathies of the quadriceps tendon, the pes anserinus on the medial tibial side or the tractus iliotibialis on the lateral side. Similar to the aforementioned multimodal treatment, therapy involving extracorporeal shockwave treatment (ESWT), low-level laser therapy (LLLT) and polidocanol sclerosing therapy are potential treatment options in knee-related tendinopathies in wakeboarding.

24.4 Illnesses

24.4.1 Sun Burns and Skin Cancer

Ultraviolet radiation (UV) is a significant and important risk factor for both nonmelanoma and melanoma skin cancer. Outdoor athletes in particular are exposed to considerable UV dosage, due to both direct radiation and the sun's rays reflected from the sea or water surface in wakeboarding. Large epidemiological studies showed that recreational activities such as sun exposure on the beach or during water sports were associated with an increased risk of basal cell carcinoma, whereas skiing has been shown to be at increased risk for squamous cell carcinoma. Risk factors for cutaneous melanoma, such as the number of melanocytic nevi and solar lentigines, have been found to be more frequent in subjects practising endurance outdoor sports [18]. According to the authors, protective measures such as avoiding training and competition in conditions with considerable sun exposure, choosing adequate clothing and applying water-resistant sunscreen still need to be more widely adopted in the community of wakeboarding athletes.

24.4.2 Waterborne Infections

It seems that water sports might be associated with a risk of waterborne infections, depending on geographical location. Primary amebic meningoencephalitis (PAM) is a fatal, free-living amebic infection of the central nervous system, caused by Naegleria fowleri, found particularly in the southern regions of the USA. Recommended strategies for the prevention of PAM include a combination of public health education and behavioural modification, and freshwater wakeboarding has been postulated as a significant risk factor for PAM [19].

24.5 Prevention

Sport-specific injury reduction training may be an important measure in preventing wakeboarding injuries. In particular, training in the movements involved in the more complex manoeuvres should be done gradually, first on land and then on the board without bindings to reduce the leverage of the board in the water [6]. Increased fitness, coordination, proprioception and muscle balance may also play a preventative role [14]. With regard to overuse injuries affecting the knee tendons, eccentric training (e.g. on a 25° decline board [20, 21]) may be implemented to potentially reduce the risk for patella tendinopathies in wakeboarding athletes. The trajectory of obstacles such as kickers should be taken into consideration during construction, with longer and flatter jumps preferred to shorter and steeper models, thus increasing the potential for safer landings. Injury prevention in cable wakeboarding has to address the training of jumps and tricks and the construction of obstacles and ramps [6]. Given the aforementioned potentially substantial injuries, such as hand amputation following strangulation in the wakeboarding cable, preventive issues might be considered. As far as wakeboarding is concerned, device-related issues might be discussed. The creation of releasable wakeboarding bindings poses the problem that detachment of only one foot makes the board uncontrollable, and a significant lever arm would be generated on the remaining attached leg. For this reason, new quick-release mechanisms allowing for the simultaneous release of both feet from the board at a preset force have recently been developed [22]. Although back protectors are highly recommended while wakeboarding, further evaluation of the real effectiveness of helmets in preventing injuries is necessary before any meaningful recommendations can be made. Indeed a helmet may be ineffective against rotational or deceleration forces acting in wake boarding: helmets also increase the cross-sectional area of the head as well as its resistance in the water and as a consequence increase the deceleration forces due to the water immersion [7]. The consumption of alcohol and drugs should absolutely be avoided before practising wakeboarding, since these substances lower inhibitions and reduce coordination and reaction times [6]. Finally, as far as wakeboarding-associated illnesses such as sunburn and skin cancer are concerned, UV protective gels and equipment might be a reasonable option in this outdoor sport.

References

1. Sport & Fitness Industry Association. https://www.sfia.org/reports/364_Wakeboarding-Participation-Report-2015. Accessed on June 2015.
2. Carson WJ. Wakeboarding injuries. Am J Sports Med. 2004;32(1). doi:10.1177/0363546503258910.
3. Su JW, Lim CH, Tan JL, Chua YL, Chui PP. Wakeboarding -related water impact trauma as a cause of fatal cardiac rupture. J Thorac Cardiovasc Surg. 2007;134(2):506–7.
4. Baker JI, Griffin R, Brauneis PF, Rue LW, McGwin G. A comparison of wakeboard-, water skiing-, and tubing-related injuries in the United States, 2000–2007. J Sports Sci Med. 2010;9(1):92–7.
5. Hostetler SG, Hostetler TL, Smith GA, et al. Characteristics of water skiing-related and wakeboarding-related injuries treated in emergency departments in the United States, 2001–2003. Am J Sports Med. 2005;33:1065–70.

6. Patzer T, Hrabal SA, Timmesfeld N, Fuchs-Winkelmann S, Schofer MD. Verletzungsarten und Verletzungshäufigkeiten beim Cable-Wakeboard: eine prospektive saisonbegleitende Studie Incidence and Mechanism of Injuries in Cable-Wakeboarding, a Prospective Study. Sportverl Sportschad. 2009;23: 141–7. doi:10.1055/s-0028-1109712.
7. Chia JK, Goh KY, Chan C. An unusual case of traumatic intracranial hemorrhage caused by wakeboarding. Pediatr Neurosurg. 2000;32(6):291–4.
8. Fridley J, Mackey J, Hampton C, Duckworth E, Bershad E. Internal carotid artery dissection and stroke associated with wakeboarding. J Clin Neurosci. 2011;18:1260–1. doi:10.1016/j.jocn.2011.02.013.
9. Lim CT, Wee J, Lee KT. Early surgical treatment of pectorals major tendon rupture: a case report. Malays Orthop J. 2012;6:38–40. doi:10.5704/MOJ.1211.009.
10. Pascual-Garrido C, Swanson BL, Bannar SM. Closed proximal muscle rupture of the biceps brachii in wakeboarders. Knee Surg Sports Traumatol Arthrosc. 2012;20(6):1019–21.
11. Knobloch K, Gohritz A, Altintas MA, Spies M, Vogt PM. A wakeboarding injury presented as acute carpal syndrome and median nerve contusion after wrist strangulation: a case report. Cases J. 2009;2(1):100.
12. Woodacre T, Marshall M. Traumatic hand amputation while wakeboarding. BMJ Case Rep. 2011;3:2011.
13. Woodacre T, Marshall M. Unusual presentation of more common disease/injury: traumatic hand amputation while wakeboarding. Emerg Med J. 2011;28(10): 896–7. doi:10.1136/emj.03.2011.4044rep.
14. Starr HM, Sanders B. Anterior cruciate ligament injuries in wakeboarding: prevalence and observations on injury mechanism. Sports Health. 2012;4(4):328–32.
15. Kristen K, Syré S, Humenberger M. Kitesurfen – sportmedizinische Aspekte, Risikofaktoren und Verletzungen. OUP. 2014;6:306–11. doi:10.3238/oup.2014.0306-0311.
16. Mussmann SE, Poirier JN. Snowboarder's fracture caused by a wake boarding injury: a case report. J Chioropr Med. 2010;9(4):174–8. doi:10.1016/j.jcm.2010.08.001.
17. Funk J, Srinivasan S, Crandall J. Snowboarder's talus fractures experimentally produced by eversion ad dorsiflexion. Am J Sports Med. 2003;31(6):921–8.
18. Moehrle M. Outdoor sports and skin cancer. Clin Dermatol. 2008;26(1):12–5.
19. Diaz J. Seasonal primary amebic meningoencephalitis (PAM) in the south: summertime is PAM time. J La State Med Soc. 2012;164(3):148–50.
20. Young MA, Cook JL, Purdam CR, Kiss ZS, Alfredson H. Eccentric decline squat protocol offers superior results at 12 months compared with traditional eccentric protocol for patellar tendinopathy in volleyball players. Br J Sports Med. 2005;29(2):102–5.
21. Purdam CR, Jonsson P, Alfredson H, Lorentzon R, Cook JL, Khan KM. A pilot study of the eccentric decline squat in the management of painful chronic patellar tendinopathy. Br J Sports Med. 2004;38(4):395–7.
22. Ball et al. United States Patent Application Publication No. US 2014/0162511 A1; 2014:1–5.

Extreme Scuba Diving Medicine

25

Simon J. Mitchell and David J. Doolette

25.1 Introduction

Diving using self-contained underwater breathing apparatus (scuba) is a popular recreational activity. Participants are drawn from most age groups (children to elderly) and both genders. There are well-established agencies which provide training courses for diving at entry and more advanced levels, and there is a substantial industry involving equipment manufacturers and travel providers. The vast majority of recreational divers perform short, relatively shallow dives using a single cylinder of compressed air in order to participate in what could be referred to as 'underwater sightseeing'. Many recreational divers include activities such as seafood harvesting or photography in their dive plans.

There is a much smaller subgroup of 'extreme' recreational divers who use a suite of advanced diving techniques (often referred to as 'technical diving') to visit deeper depths or remain underwater longer (or both) [1, 2]. The relevant techniques have some similarities to those used for occupational (commercial and military) diving to deep depths and some important differences. Commercial diving to depths frequented by technical divers is typically conducted by divers who live for weeks at a time inside a dry, shipboard chamber at a pressure close to the pressure at the depth of the worksite. Divers commute to the worksite in a pressurised diving bell and make excursions into the sea to perform underwater work but remain connected to the diving bell by an umbilical that provides breathing gas, heating, power and communications. Divers are only exposed to the physiological stresses of decompressing back to sea level pressure once at the end of the job. This type of diving is prohibitively expensive for a recreational activity, and technical divers undertake what are commonly referred to as 'bounce dives' – that is, the descent and a relatively short period at depth are followed immediately by decompression back to the surface – and technical divers always use scuba. In this respect, technical diving has some similarities to military underwater mine countermeasure diving. However, this latter task motivates spending as short a time as possible in the water exposed to the minefield, whereas technical divers seek to maximise the time they can spend at depth.

This chapter is primarily intended to describe the methods and challenges relevant to technical divers, but it begins (for perspective and contrast) with a brief description of the features of the underwater environment relevant to all divers and a very brief account of conventional recreational diving.

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25.2 The Underwater Environment and Its Challenges

Any form of swimming involves immersion in a dense non-respirable medium with high thermal conductivity that is frequently cold and which is subject to surges and currents. These characteristics of the aquatic environment are relevant to diving also, but most of the unique challenges and problems associated with underwater swimming arise from the changes in pressure that occur during descent and ascent through the water column. For every 10.13-m increase in depth of seawater, the ambient pressure (P_{amb}) increases by 1 atmosphere (atm) (101.3 kPa). Thus, a diver at a depth of 10 m of seawater (msw) is exposed to a P_{amb} of approximately 2 atmospheres absolute (atm abs), 1 atm exerted by atmospheric air above the water and 1 atm exerted by the weight of water above the diver. Similarly, a diver at 20 msw is exposed to a P_{amb} of 3 atm abs, a diver at 30 msw is exposed to a P_{amb} of 4 atm abs and so on. The term 'absolute' is used to distinguish from 'gauge' pressures which ignore the pressure exerted by atmospheric air – gauge pressures are commonly used in diving, for instance, when P_{amb} is given in equivalent depth of seawater. The important effects of this exposure to increased P_{amb} can be subdivided broadly into effects on compressible air spaces and effects on gas physiology.

25.2.1 Pressure Effects on Compressible Air Spaces

A diver has several anatomical air spaces which are subjected to the pressure changes associated with descent and ascent. Most important are the middle ear spaces which must be equalised with airway gas via the Eustachian tubes during changes in depth. This usually requires an active manoeuvre like a 'Valsalva' during descent but occurs passively during ascent. Failure to equalise pressure in the middle ear can lead to barotrauma in which there is an effusion or bleeding behind the tympanic membrane or even perforation of the membrane. The sinus spaces may be affected in much the same way though equalisation through widely patent sinus ostia usually occurs without any active intervention by the diver [3].

The lungs are also susceptible to barotrauma. During descent on a compressed gas dive, the pressure in the lungs is automatically compensated because the breathing apparatus supplies respired gas at P_{amb}. However, if gas becomes trapped in the lungs (or a segment of the lung) during ascent, then expansion of that gas as P_{amb} decreases may result in over-distension of the lung tissue. This, in turn, can lead to pneumothorax, mediastinal emphysema or the introduction of gas into the pulmonary veins (Fig. 25.1). The resulting bubbles in the systemic circulation can cause embolic injury to vulnerable organs such as the brain [4].

25.2.2 Pressure Effects on Gas Consumption and Gas Physiology

Scuba equipment supplies the diver with gas at P_{amb}, and gas density therefore increases in direct proportion to P_{amb} as the diver ventures deeper. This has two implications. First, the work of breathing is increased, and this will be further discussed later in this chapter. Second, since more molecules of gas occupy the same volume at higher pressures, gas is consumed at a rate that also increases proportionally to P_{amb}. For example, at 30 msw (4 atm abs) a diver could expect to consume their gas supply twice as fast as at 10 msw (2 atm abs) or four times as fast as at the surface (1 atm abs).

Breathing air (nitrogen 78 %, oxygen 21 %) at elevated P_{amb} results in respiration of oxygen and nitrogen at higher partial pressures than normal. In both cases this can have important consequences.

Oxygen breathed at elevated pressures can result in cerebral irritability and seizures with little or no warning; a phenomenon commonly referred to as 'cerebral oxygen toxicity'. This is particularly dangerous because loss of consciousness underwater will often lead to drowning. The

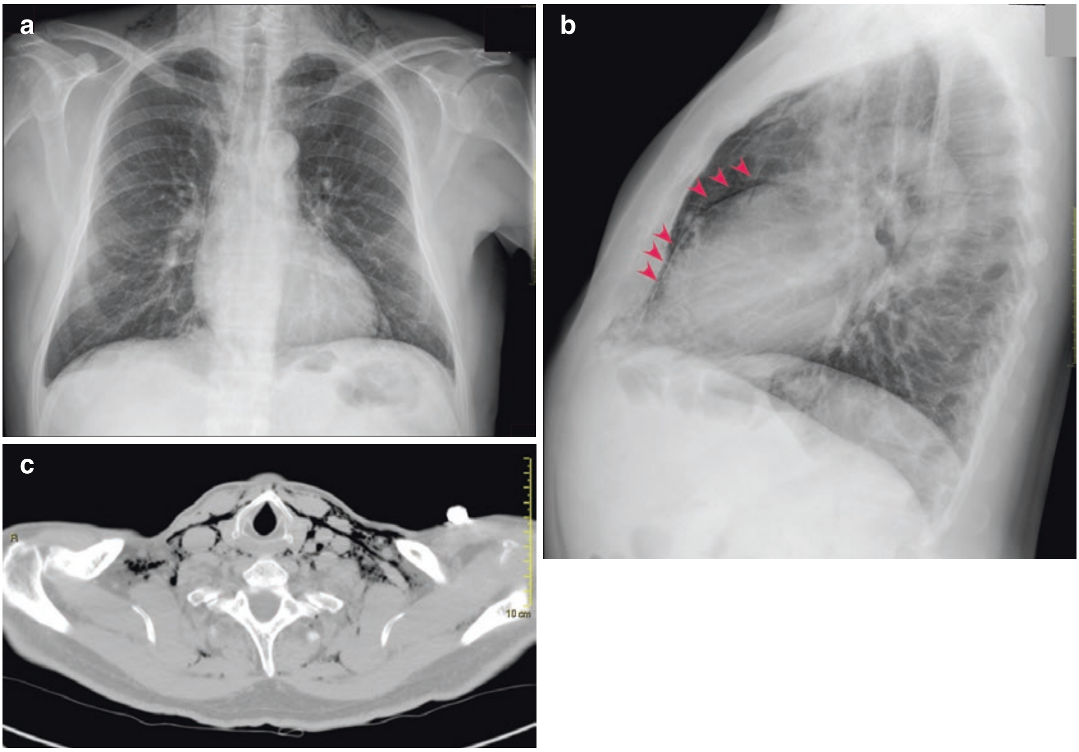


Fig. 25.1 Mediastinal emphysema and subcutaneous emphysema of the neck in a diver resulting from a rapid ascent from about 40 m with closed glottis. Plain radiographs (**a**, **b**) and CT scan (**c**). *Arrows* in image B identify mediastinal gas. (Courtesy of Dr Feletti, own case series)

mechanism of oxygen toxicity is poorly understood, though risk increases with inspired PO_2 (P_iO_2) and the duration of the exposure [5]. There is no clear threshold P_iO_2 known to be invariably safe, though there is broad consensus that a P_iO_2 of 1.3 atm abs is relatively safe, even for long duration exposures. This is discussed further below, but in the context of the present narrative, avoidance of a P_iO_2 of greater than 1.3 atm abs effectively limits the use of air as a breathing gas to depths less than 52 msw (where the $P_{amb} = 6.2$ atm abs, and the P_iO_2 when breathing air is therefore $6.2 \times 0.21 = 1.3$ atm).

Nitrogen breathed at elevated pressures produces a narcotic effect, often referred to as 'nitrogen narcosis' that increases progressively with the P_iN_2. This effect becomes noticeable at depths greater than 30 msw ($P_{amb} = 4$ atm abs), but it is probably present at shallower depths. There is no universal consensus on a threshold depth beyond which nitrogen narcosis becomes intolerable, but diving with air beyond 40–50 msw is often considered inappropriate for this reason. It should be obvious that cognitive impairment due to nitrogen narcosis could predispose towards incidents [6].

The respiration of gases at elevated pressures results in greater absorption into blood and tissues as predicted by Henry's law. During ascent, bubbles can form from this accumulated gas. These bubbles may be intravascular (appearing first in the venous system because it is the venous blood 'draining' from tissues that is supersaturated), or they may form within the tissues themselves. Depending on the site and profusion of these bubbles, they may cause symptoms of decompression sickness (DCS) (often referred to as 'the bends'). Venous gas bubbles are routinely detected by ultrasonic methods (venous gas emboli: VGE) after dives that do not result in DCS. However, there is substantial evidence that divers with large right to left shunt pathways

Fig. 25.2 Typical recreational scuba air diver. Note the single cylinder of compressed air and the use of an open-circuit regulator with loss of exhaled gas into the water

(such as a patent foramen ovale) are more vulnerable to developing serious neurological symptoms, implying that VGE can become harmful if they reach the arterial circulation. There are probably many mechanisms by which intravascular and extravascular bubbles can cause pathological effects, including direct mechanical effects, micro-vessel obstruction and activation of coagulation and other complex inflammatory processes. The pathophysiology of this condition is complex and beyond the scope of this chapter. It is described in more detail elsewhere [7, 8]. Symptoms can range from non-serious (such as fatigue, rash, pain) to serious (such as paralysis, cardiopulmonary collapse) [9].

25.3 Recreational Scuba Air Diving

The most common scuba configuration for recreational diving is a single cylinder of compressed air worn on the back with a 'regulator' which reduces the cylinder air pressure to P_{amb} and supplies air during inhalation. The diver exhales into the surrounding water. Divers also require a mask (for vision) and fins (for underwater propulsion), and diving in temperate water usually requires the use of thermal protection in the form of a wet suit or dry suit. Most divers wear some form of buoyancy control device, effectively an inflatable water wing to which compressed air can be added (or removed) thus making the diver more (or less) buoyant. A diver wearing an equipment configuration typical of recreational air diving is shown in Fig. 25.2.

Recreational scuba air divers are taught to perform 'no-decompression' dives. That is, they are instructed to perform dives where nitrogen absorption into tissues is limited so that a direct ascent to the surface (at a rate not exceeding 9 m/min) is possible at all times during the dive. If the time/depth profile of a dive exceeds so-called no-decompression limits, then decompression stops to allow more time for tissue gas elimination must be made during the ascent. Most divers carry a dive computer that incorporates a timer, a pressure sensor, a microprocessor and an output screen and which continually updates a decompression algorithm and informs the diver how much time they have remaining at the current depth before an ascent with decompression stops becomes necessary. If the no-decompression time is exceeded, then the computer will prescribe the appropriate decompression stops during the ascent. With avoidance of the need for decompression stops and some of the other issues discussed above in mind, recreational diver training organisations usually recommend 40 msw as the maximum depth for scuba air diving.

Despite the seemingly daunting challenges above, recreational scuba air diving is a relatively safe sport. A training database maintained by the Professional Association of Diving Instructors indicates a fatality rate on scuba air training dives of 0.5 deaths per 100,000 dives [10]. Estimates of mortality and nonfatal decompression sickness in non-training scuba air dives are two per 100,000 and ten per 100,000 dives, respectively [11].

25.4 Technical Diving

There is a relatively small group of 'technical divers' who perform 'extreme' scuba dives beyond the depths and/or durations of typical recreational dives, typically for the purposes of reaching a deep shipwreck or exploring a long-flooded cave. Dives to depths of about 90 msw have become relatively common in this context, and some dives have exceeded 300 msw. Dives in caves lasting well over 12 h have been undertaken.

The challenges involved in the conduct of deep and/or long dives can be predicted from the preceding discussion and include:

1. Reducing the narcotic effect of nitrogen in the respired gas
2. Reducing the toxic effect of oxygen in the respired gas
3. Managing the density of the respired gas
4. Decompressing as quickly as possible while keeping the risk of decompression sickness low
5. Carrying enough gas for very long duration dives
6. Complex logistics including gas supplies and surface support and achieving adequate thermal protection

25.4.1 Mixed Gas Diving: The Pivotal Role of Helium

The first three of these challenges can be met by use of breathing gas mixes containing helium. Helium is a light inert gas that does not produce narcosis at elevated partial pressures. Thus, substituting helium for at least some of the nitrogen in the breathing gas ameliorates both the narcosis and density problems. This typically results in the diver breathing 'trimix': a combination of oxygen, helium and nitrogen. Technical divers define the particular mix by stating the fraction of oxygen and helium present. For example, 'trimix 8:60' would consist of 8 % oxygen and 60 % helium, and the unstated balance (32 %) is nitrogen.

Nitrogen is rarely substituted completely with helium for several reasons. One is the high cost of helium. This is less of an issue when using a rebreather which recycles exhaled gas (see later), but in open-circuit diving (where all exhaled gas is lost to the water), pure oxygen–helium mixtures (heliox) would be very expensive to use. In addition, some decompression models tend to penalise the use of high helium fractions by mandating longer decompressions. Although this may be unnecessary (see later), it remains a consideration for many divers in planning their gas mixes. Finally, in very deep dives beyond 150 msw, the inclusion of nitrogen in the breathing mix helps to ameliorate the high-pressure neurological syndrome (HPNS) which can cause troublesome tremors and cognitive impairment. HPNS is thought to be due to a pressure effect on excitable membranes, and the dissolution of highly soluble nitrogen into those membranes has an ameliorating effect which is not fully understood [6].

The 'recipe' for the optimal trimix for use during the deepest portion of the dive is based on the planned depth, the duration of the dive, the diver's perception of the maximum safe inspired PO_2 and the maximum tolerable narcotic effect. For example, in considering a dive to 90 msw (10 atm abs), the first decision is how much oxygen the mix should contain. Divers will usually aim to breathe as much oxygen as is considered safe, since breathing more oxygen means less inert gas uptake and therefore less decompression. Assuming that a maximum safe P_iO_2 of 1.3 atm (see earlier) is chosen:

$$\text{Ideal fraction of oxygen in the mix} = 1.3\ \text{atm} \div 10\ \text{atm abs} = 0.13$$

The mix would therefore contain 13 % oxygen for breathing at 90 msw.

The second decision is the amount of nitrogen in the mix. A common basis for this decision is the degree of narcosis that the diver is prepared to tolerate which in turn is notionally 'calibrated' on a comparison with air diving. Thus, assuming a diver is comfortable with the level of narcosis experienced during air diving at 40 msw, they might aim to breathe an equivalent PN_2 during the deepest phase of a trimix dive. This is easily calculated by multiplying the fraction of nitrogen in air (0.78) by the ambient pressure at 40 msw (5 atm abs) which gives a PN_2 of 3.95 atm. Therefore:

$$\text{Acceptable fraction of nitrogen in the mix} = 3.95\ \text{atm} \div 10\ \text{atm abs} = 0.4$$

The trimix should therefore contain 40 % nitrogen. This calculation assumes oxygen is not narcotic, but a more conservative approach assuming equal narcotic potency of oxygen and nitrogen yields only a small difference. Having calculated the ideal fractions of oxygen (FO_2) and nitrogen (FN_2) for the trimix, the helium content (FHe) simply makes up the balance, thus:

$$\text{Fraction of helium required} = 1 - FN_2\left(0.4\right) - FO_2\left(0.13\right) = 0.47$$

This planning process has determined that an appropriate trimix for a dive to 90 msw is 13 % oxygen, 47 % helium and 40 % nitrogen, designated trimix 13: 47. Another parameter often forgotten in such planning is the density of the resulting gas at the target depth. There is an increasing risk of CO_2 retention as the inspired gas density increases, and this result can have life-threatening consequences (see later). It follows that there are sound reasons for ameliorating risk factors for hypercapnia, of which density is one; but there is no clear consensus on the upper density limit. Testing of equipment with gas at a density of 8 g L^{-1} has seen this figure sometimes cited, but recent (and as yet unpublished) data suggest a risk inflection for CO_2 retention around a density of 6.2 g L^{-1}. Calculation of gas density at a target depth is easily achieved based on proportions and adjustment for P_{amb} if given the following densities (g L^{-1}) at 1.0 atm abs: oxygen 1.43, nitrogen 1.25 and helium 0.18. In the above example, trimix 13: 47 at 90 msw (10 atm abs) would have a density of 7.7 g L^{-1}. To comply with a 6.2 g L^{-1} recommendation, the mix could be adjusted to trimix 13: 60. The respiratory physiology of extreme deep diving is the first of two focus areas treated in more detail later in this chapter.

25.4.2 Decompressing as Quickly as Possible While Keeping the Risk of Decompression Sickness Low

Deep dives rapidly accumulate a decompression obligation (the need for decompression stops during the ascent), and it is one of the recognised travails of deep technical diving that more time (often substantially more) may need to be spent decompressing than actually on the bottom. Decompression can be a physically and mentally taxing experience, particularly when conducted in cold water and where there are environmental challenges such as wave action, currents and the onset of darkness. There is a strong motivation to minimise time spent decompressing while at the same time maintaining an acceptably low risk of DCS.

One universally employed strategy to accelerate decompression from deep dives is to increase the fraction of inspired oxygen while maintaining a safe P_iO_2 as the depth (and ambient pressure) decreases. Breathing a higher FO_2 increases the gradient for diffusion of inert gas from tissue to alveoli and thus accelerates inert gas elimination. In many cases, divers choose a breathing mix with less or no helium in the shallower depths during decompression because helium's low density and non-narcotic properties are no longer necessary. This also saves on the cost of this expensive gas, especially in open-circuit diving. In addition, merely switching from helium to nitrogen is also perceived to accelerate decompression (see later). Thus, divers frequently breathe so-called 'nitrox' mixes during decompression. Nitrox is a mix of oxygen and nitrogen with a fraction of oxygen higher than that in air. The mixes are named for the fraction of oxygen (nitrox 32 is 32 % oxygen and 68 % nitrogen). Thus, for example, during ascent a diver might switch to breathing nitrox 32 at 30 msw where the P_iO_2 would be 1.3 atm. There might be further changes to progressively 'richer' oxygen mixes, culminating in a final decompression stop at 3 msw conducted breathing pure (100 %) oxygen (where the P_iO_2 would also be 1.3 atm).

25.4.3 Carrying Large Gas Supplies or Extending Gas Supply

In order to undertake deep decompression dives, extreme divers must carry much greater supplies of gas or a means of extending a limited supply of gas. For open-circuit divers this inevitably means carrying multiple cylinders of gas during the dive (Fig. 25.3) and, in some cases, staging more cylinders of gas at strategic points on preliminary dives so that they are there for use on the 'main dive'. The accurate planning of the required gas volumes for deep and/or long dives is one of the most critical skills for a technical diver but will not be described in more detail here.

Fig. 25.3 Technical diver conducting a decompression stop. The two regulators from the diver's twin, back-mounted cylinders are stowed, and diver is breathing from one of two 'stage' cylinders of decompression gas mixtures carried clipped to his harness. The reel of line is connected to a surface marker buoy that the diver deployed so that the surface vessel can track the dive team during a free-floating decompression. Note the diver propulsion vehicle which is not in use and is stowed. (Photo courtesy of A. Hagberg.)

The increasing use of rebreathers for the purpose of reducing gas consumption is arguably the most important development in technical diving over the last decade. A rebreather is a circle circuit containing one-way check valves, one or more counter-lungs, a CO_2 absorbent canister and systems for maintaining both the volume of the circuit and an appropriate inspired PO_2. Rebreathers are categorised by the nature of the system for maintaining the inspired PO_2, and it is beyond the scope of this chapter to detail the operation of all of them. The most prevalent is the so-called electronic closed-circuit rebreather (eCCR). The typical (and simplified) functional layout of one of these devices is shown in Fig. 25.4, and divers wearing rebreathers are shown in Fig. 25.5.

During use, the diver exhales into the counter-lung through a CO_2 absorbent and then inhales from the counter-lung. The one-way check valves in the mouthpiece ensure that flow around the circuit is unidirectional. Three galvanic fuel cells are exposed to the gas in the circuit. These are essentially oxygen-powered batteries that produce an electric current directly proportional to the PO_2 to which they are exposed. After calibration against a known PO_2, the averaged output of the three cells indicates the circuit PO_2, and this is constantly monitored by a microprocessor. A target P_iO_2 (PO_2 'set point') is selected by the diver, and as oxygen consumption reduces the circuit PO_2 below this target, the microprocessor opens an electronic solenoid valve to allow oxygen into the circuit to restore and maintain a relatively constant PO_2 near the set point. This set point is typically 0.7 atm at the surface and is increased to a higher target (such as 1.3 atm) once the dive is underway.

Fig. 25.4 Schematic layout of a typical electronic closed-circuit rebreather. Note, for clarity, the oxygen sensors are portrayed as being located in the counter-lung, but this is never the case. See text for further explanation

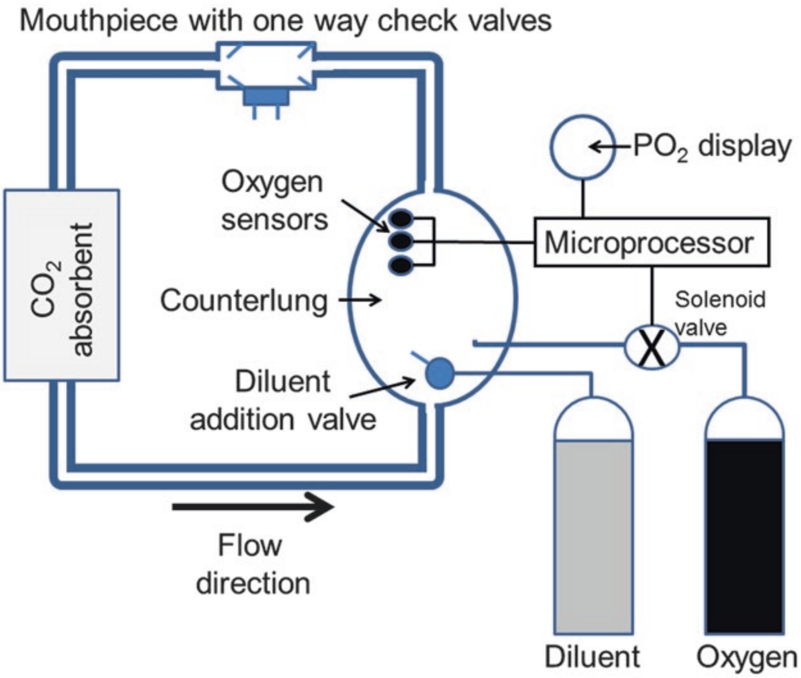
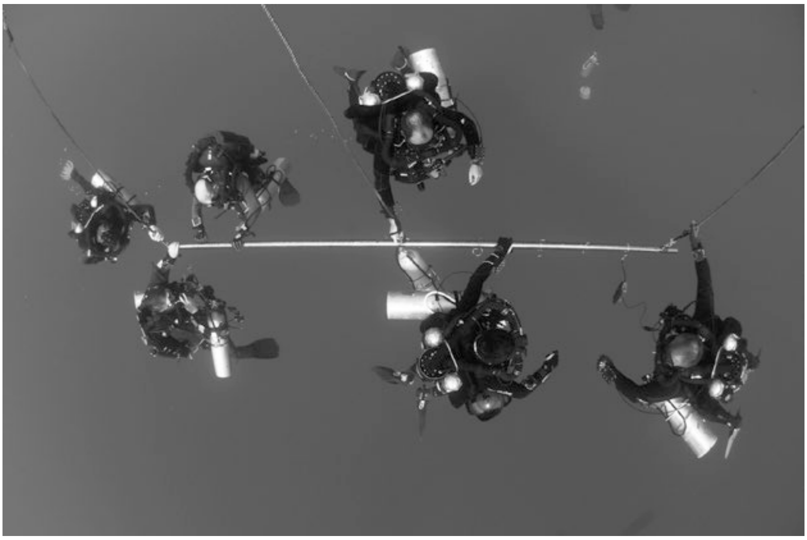


Fig. 25.5 Rebreather divers on a decompression station. Note the open-circuit scuba 'bailout' cylinders carried by all divers



The volume of the circuit is maintained as P_{amb} increases during descent by the addition of a diluent gas. When the counter-lung is compressed, the diver will begin to generate a negative pressure in the circuit during inhalation. This opens a mechanical diluent addition valve (Fig. 25.4) allowing diluent gas into the circuit and restoring its volume. For safety reasons, the diluent gas typically contains a fraction of oxygen high enough that the gas is breathable but low enough that the circuit PO_2 can still be lowered to the desired set point at the deepest point in the dive. For a dive to less than 50 msw with a PO_2 set point of 1.3 atm, air could be used as the diluent gas. Its oxygen fraction of 0.21 still allows a circuit PO_2 of ~1.3 atm at 50 msw (ambient pressure of 6 atm abs × 0.21 = 1.26 atm), and at shallower depths the rebreather will add oxygen to maintain the P_iO_2 at 1.3 atm. Thus, the diver will be breathing a nitrox mix whose oxygen and nitrogen content varies with depth but whose P_iO_2 remains constant. For a deep dive the diluent gas (usually trimix) is chosen using virtually the same principles as described earlier for mixed-gas diving.

It should be obvious that the crucial advantage of a rebreather is the recycling of exhaled gas thus preserving expensive components like helium. Indeed, the use of diluent gas effectively ends on arrival at the deepest depth provided there is no up-and-down depth variation from that point on. In contrast to open-circuit diving, gas consumption changes little with depth, and the absolute amounts of gas used are vastly smaller.

Another major advantage of rebreathers is the breathing of the optimal safe inspired fraction of oxygen for minimising inert gas uptake and for accelerating decompression throughout the dive. In open-circuit diving, for each gas carried the inspired fraction of oxygen can only be optimal at one depth. Thus, in the example cited earlier, if a P_iO_2 of 1.3 atm is considered safe, then nitrox 32 breathed during decompression is only an optimal decompression gas at 40 m. On ascent to shallower depth, the P_iO_2 falls, and the fraction of inspired oxygen is no longer as high as it can safely be (and therefore no longer optimal). In contrast, an eCCR will raise the inspired fraction of oxygen to maintain the 1.3 atm PO_2 set point throughout the ascent.

Other rebreather advantages include the breathing of warm, humidified gas and production of few or even no bubbles. The major disadvantages are that the devices are complex, costly and maintenance intensive, provide numerous opportunities for user error and have many potential failure points. Arguably the most significant of these is the oxygen cells which are 'consuming' and therefore have a limited and somewhat unpredictable life. Inaccurate data from oxygen cells has been the root cause of many accidents. This potential for failure mandates the requirement for access to open-circuit gas supplies (commonly referred to as 'bailout') appropriate for all depths visited and adequate to allow decompression from any point of the dive plan. Planning the carriage of bailout gases is very similar to the planning of an open-circuit deep dive described above. Notwithstanding this precaution, it is perhaps not surprising that crude estimates suggest that rebreather diving is associated with higher mortality (perhaps an order of magnitude higher) than open-circuit diving [12].

25.4.4 Logistics of Technical Diving

Technical diving frequently involves complex logistics to support these ambitious dives. Deep wrecks usually lie in open ocean, and diving them requires large boats for safe and reliable surface support in weather conditions that are rarely optimal. Accurate GPS and sounding equipment are vital, and teams develop considerable skill in accurately dropping a shot line down on to a wreck in deep waters. Divers usually descend and ascend on these shot lines, and purpose-built decompression stages with bars at the depths of the long stops help divers accurately maintain stop depths and allow multiple divers to comfortably occupy the station at the same depth (Fig. 25.5). However, strong currents can complicate such plans and necessitate the use of live boating, where the divers descend from an unanchored surface vessel up-current of the target and complete decompression drifting underneath a surface marker buoy so that the divers do not have to hold onto a shot line against the force of the current. To enhance safety, teams often arrange themselves into bottom diver and support diver roles. Bottom divers actually visit the wreck, and support divers help with surface logistics and visit the bottom divers during decompression. This allows any developing needs to be met and messages to be relayed to the surface.

The exploration of long and frequently deep caves has a different set of logistical challenges. Sequential dives, often very dependent on the use of battery-powered diver propulsion vehicles, are used to penetrate progressively further into the cave and to lay lines into new sections. As there is progress to greater distances, it may become necessary to stage gas supplies at strategic points on the way in before ‘pushing’ the cave further. In this setting, divers may arrange themselves into large teams with specific roles for each individual. Lead divers perform the long pushes. Setup divers may be required to stage gas prior to the dive, and support divers visit the lead divers during their decompression which, as in deep wreck diving, allows any developing needs to be met and messages to be relayed to the surface. In some major cave penetrations, support divers may even install dry underwater habitats (such as an upside-down rainwater tank filled with air) in which the lead divers can actually leave the water while still under pressure in order to rest, eat, drink and warm up.

In both wreck and cave settings, there are numerous logistical considerations which are vitally important but too numerous to discuss here. These include thermal protection and temperature management, hydration and nutrition, gas logistics, medical support and evacuation plans. It should be obvious from this discussion that merely training in the technical diving methods described above is only the start of the process of becoming an exploration-level technical diver.

25.4.5 Current Scope of Technical Diving

The boundary between technical diving and mainstream recreational diving is fluid because technical diving methods and equipment are adopted by and become part of recreational diving [13]. It is difficult to imagine now, but the use of nitrox, presently considered ‘mainstream’ in recreational diving, was viewed as highly technical and fiercely opposed by the recreational diving industry in the early 1990s. In what may prove to be a similar development, there are current plans to develop and promote simplified closed-circuit rebreathers for mainstream recreational diving.

Open-circuit and rebreather trimix dives to a maximum of about 90 msw for bottom times of 30–60 min represent the current state of typical technical diving. Several training agencies specialise in training for this type of diving and several of the large recreational training agencies have also entered this market. Depth record-setting dives (now in excess of 300 msw on open-circuit equipment) typically involve immediate ascent from the maximum depth. However, technical divers are conducting purposeful cave exploration dives in excess of 200-m fresh water (mfw) with substantial bottom times. A notable recent example is the exploration of the Pearse Resurgence cave system in New Zealand to 221 mfw. In addition, some dives of remarkable duration are now being undertaken to explore caves over long distances. The most conspicuous are those conducted by the Woodville Karst Plains Project in northern Florida. This team has conducted exploration out to 7.9 km in Wakulla Springs, a dive requiring 11 h of bottom time at an average depth of 80 mfw, followed by 16 h of decompression.

As technical divers have extended these boundaries deeper and longer, a number of physiological challenges have been pushed into the spotlight, often because of related accidents. This chapter concludes with a more detailed discussion of two such challenges: the respiratory implications of deep diving and issues pertaining to decompression from deep dives.

25.4.6 Respiratory Challenges of Deep Diving

Breathing in the underwater environment invariably requires greater work to achieve lung ventilation than during breathing at the surface. There are multiple potential contributors to this increased work [14].

First, the use of underwater breathing apparatus imposes an external breathing resistance that is not present during normal ventilation. The degree of impediment depends on the type and design of the device. In general, a well-tuned high-quality open-circuit regulator provides less external resistance than a rebreather device because during inhalation, once the demand valve is tripped, the supplied gas flows relatively freely. In addition, exhalation is via a simple mushroom valve to the external environment. In contrast, in a rebreather the diver must generate all the work necessary to move gas through the hoses, valves and CO_2 absorbent. Based on evaluation of the influence of work of breathing on dyspnea and CO_2 retention (see later), Warkander et al. (1992) proposed that the external work of breathing for UBA should not exceed 1.5–2.0 J/L in the ventilation range of 30–75 L/min [15].

Second, the increase in gas density that occurs as gas is respired at higher ambient pressure increases the resistance to flow through both the diver's airways and the orifices, hoses and valves of the UBA. Not only does this further increase work of breathing, it also predisposes to the onset of dynamic airway compression during exhalation at much lower flow rates than normal [16]. Since the pressure drop along the airway occurs more quickly when exhaling a dense gas, the equal pressure point will be reached more proximally and at lower flow rates during a forced exhalation. Not surprisingly, the maximum voluntary ventilation is markedly reduced as depth increases [14]. For example, during air breathing, maximum voluntary ventilation is halved at 4 atm abs (30 msw equivalent) compared to 1 atm abs, even when measured with low-resistance respiratory laboratory equipment. In what is probably a subconscious attempt to reduce dynamic airway collapse, divers breathing dense gas tend to increase their expiratory reserve volume. This increases the calibre of small airways by stretching them, but it also shifts tidal breathing to a less favourable part of the lung compliance curve, further increasing the work of breathing [17].

Third, during immersion there is the potential for development of so-called static lung loads (SLLs). These exist if the gas pressure inside the airway is either higher (positive SLL) or lower (negative SLL) than the external water pressure at the level of the notional lung centroid [18]. For example, in the upright diver using an open-circuit UBA, there will be a negative SLL because the gas is supplied by the regulator at ambient pressure at the depth of the mouth, whereas the lung centroid will be approximately 25 cm H_2O deeper. This is similar to head-out immersion. Similarly, a negative SLL exists for a rebreather diver swimming horizontally if the counter-lung is on the back (shallower than the lung centroid). A negative static lung load probably makes premature dynamic airway closure more likely during exhalation [19], and it also promotes engorgement of the distensible pulmonary circulation by blood thus reducing lung compliance and increasing work of breathing [18].

The most important physiological consequence of these changes in work of breathing is disturbance of CO_2 homeostasis. In particular, there is a tendency to the development of hypercapnia during diving [14, 20]. The most important contributing factor is probably the increase in work of breathing described above, and this interacts with other physiologic, circumstantial and equipment factors as follows:

First, there appears to be substantial interindividual differences in the behaviour of the respiratory controller when there is an increased requirement for respiratory work to maintain normocapnia. Thus, some subjects maintain normocapnia as the work of breathing increases during a dive, whereas others don't; it is as though the respiratory controller 'prefers' to allow hypercapnia over the alternative of driving the extra work required to keep the P_aCO_2 normal [21]. This phenomenon is often referred to as 'CO_2 retention', and vulnerable individuals are deemed to be 'CO_2 retainers'. The tendency is maximally unmasked at precisely the point in the dive when it is most dangerous (at deep depth, breathing dense gas and exercising), and it may be exacerbated by breathing oxygen at an elevated inspired PO_2 (which, as previously described, is the norm in technical diving).

Second, in rebreather diving it is possible for the CO_2 absorbent to fail to remove all expired CO_2 so that CO_2 is subsequently re-inhaled. Under normal (non-diving) circumstances, normocapnia can be maintained by an increase in minute volume despite the presence of small amounts of inspired CO_2 [22]. However, it is much less likely that such compensation will take place in the diving context where the work of breathing is concomitantly increased. Several rebreather manufacturers have recently incorporated CO_2 detectors in the inhale limb of their circuits, but this is far from universal.

Third, there is an increase in physiological dead space during diving and ventilation with hyperoxic gases [23]. The cause is probably multifactorial, though a derangement in V/Q matching is probably the most important contributor. This reduces the efficiency of any increase in ventilation effort during diving and would exacerbate any tendency to hypoventilate in the face of rising CO_2.

Finally, a rare potential contributor to disastrous hypercapnia may be encountered by divers visiting the most extreme depths. It relates to the premature onset of dynamic airway compression at very low flow rates when breathing very dense gas, particularly in the presence of a negative static lung load. These conditions can markedly reduce expiratory flow [16], potentially to the point where maximum voluntary ventilation falls below the minute volume required to maintain normocapnia. Under these circumstances the rising P_aCO_2 will drive more respiratory effort which will serve only to produce more CO_2, and the diver can enter a spiral into terminal hypercapnia. This mechanism is thought to have contributed to one widely publicised rebreather diving fatality at 264-mfw depth in which the diver videoed the circumstances of his own death [24]. Other extreme deep divers using rebreathers have reported the onset of characteristic 'coughing exhalations' when attempting to exercise at extreme depth [25] and have self-rescued by ceasing exercise and reducing depth.

Hypercapnia is dangerous for several reasons. First it may cause unpleasant symptoms such as dyspnea, headache and confusion which may progress to panic or incapacitation. Notably, it has been repeatedly demonstrated that some divers are poor at recognising the early symptoms and that incapacitation may supervene with little or no warning [26, 27]. Carbon dioxide is a narcotic gas, and its effects will be additive to those of nitrogen narcosis. Finally, hypercapnia increases the risk of cerebral oxygen toxicity, probably by causing cerebral vasodilation and thereby increasing the dose of oxygen to which the brain is exposed [28]. For these reasons, divers undertaking extreme deep dives are advised to minimise exercise during the deep phase of the dive, pay attention to projected gas densities during the planning phases of dives, ensure their equipment is optimally configured to reduce work of breathing and (in rebreather diving) to be sure to replace the CO_2 absorbent in a timely manner to ensure maximum efficiency. Rebreathers frequently incorporate a mouthpiece with a 'bailout valve' that allows switching to an open-circuit gas supply without removing the mouthpiece, a manoeuvre that has proved impossible for some dyspneic hypercapnic divers to perform [29].

25.4.7 Decompression from Technical Dives

The putative cause of DCS is excessive formation and growth of bubbles in body tissues as a result of reduction in ambient pressure (decompression). In diving, these bubbles arise from excess gas taken up while breathing compressed gas. For an animal breathing air that has not made an excursion in ambient pressure, the nitrogen in air is dissolved in the body tissues at a concentration proportional to the alveolar nitrogen partial pressure as described by Henry's law. In this state, the chemical activity of the dissolved nitrogen is described by the partial pressure (P_{N2}) of the gas in the alveoli with which it is in equilibrium. P_j is used to describe the chemical activity of any dissolved gas (j), whether or not it is in equilibrium with a gas phase. Thus P_j is equivalent to the gas partial pressure that is, or would be required, in a gas phase at equilibrium with the dissolved gas.

During a dive, alveolar inert gas partial pressures will change as a result of the changes in ambient pressure and therefore inspired gas mixture pressure and if the fractions of nitrogen, helium and oxygen in the inspired gas mixture are changed. A change in the alveolar inert gas pressures will result in the transport of that inert gas between lungs and tissues, eventually establishing a new equilibrium where alveolar and tissue partial pressures are again equal. During a typical technical dive, the result will be an increase in the sum of the dissolved gas partial pressures compared to that at the surface. Ascent from a dive can result in ambient pressure falling below the sum of the partial pressures of all gases dissolved in tissue (gas supersaturation):

$$\left(\sum P_{\mathrm{tisINERT}} + P_{\mathrm{tisO2}} + P_{\mathrm{tisCO2}} + P_{\mathrm{H2O}}\right) - P_{\mathrm{amb}} > 0 \tag{25.1}$$

where the subscript tis refers to gas dissolved in tissue and P_{H20} is the water vapour pressure at tissue temperature. If gas supersaturation occurs in tissue, bubbles may form.

The sum of all gas partial pressures inside a spherical bubble (P_{bub}) of radius r is given by:

$$P_{\mathrm{bub}} = P_{\mathrm{amb}} + 2\sigma / r + M \tag{25.2}$$

The second term on the right-hand side is the pressure increase across the gas-liquid interface due to surface tension (σ). The last term on the right-hand side is pressure exerted by displaced tissue. Assuming no pressure due to tissue displacement, assuming equilibrium between gas partial pressures inside and outside the bubble and rearranging Eq. 25.2 as an inequality give:

$$r \geq \frac{2\sigma}{\sum P_{\mathrm{tis}j} - P_{\mathrm{amb}}} \tag{25.3}$$

Equation 25.3 indicates that only bubbles above some critical radius can persist for any combination of tissue surface tension and gas supersaturation. A consequence of this is that large supersaturation is required to form bubbles de novo from dissolved gas. Gas supersaturation pressures of 190–300 atm are required to form bubbles from nitrogen or helium dissolved in pure water (which has surface tension of 0.073 N m^{-1}) [30]. These pressures are much higher than ever achieved in human diving. However, in humans, detectable venous gas bubbles follow decompression to sea level from air saturation dives to 3.6 m [31], indicating bubbles can form with supersaturation less than 0.36 atm. Bubbles could only form de novo from dissolved gas at such low supersaturation if tissue surface tensions were lower than have been measured [32]. It is therefore widely accepted that bubble forms at the supersaturation pressures encountered in human diving from pre-existing gas nuclei (theoretical proto-bubbles) [33–35].

Once formed, the bubble will shrink or grow as gas diffuses to or from surrounding tissue according to partial pressure gradients at the bubble surface. This transfer of gas across the bubble surface is given by Fick's first law:

$$\frac{d\left(P_{bub}V_{bub}\right)}{dt} = A\sum_{J=1}\left(\alpha_{ti\,sj} D_j \frac{dP_{ti\,sj}}{dr}\right) \tag{25.4}$$
$$\text{evaluated at } r = r_A$$

where V_{bub} is the volume and total gas mixture pressure inside the bubble, D_j and $\alpha_{\mathrm{tis}j}$ are the bulk diffusivity and solubility of gas j in the tissue, A is the bubble surface area and $dP_{\mathrm{tis}j}/dr$ is the gas partial pressure gradient evaluated at the bubble surface.

25.4.8 Tissue Gas Kinetics

It is clear from the description above that the physiological exchange of gases is relevant to managing the risk of DCS. This gas exchange is covered in detail elsewhere [14] and will only be summarised here. Oxygen can only be safely breathed over a relatively narrow range of inspired partial pressures, and tissue oxygen partial pressure, along with carbon dioxide partial pressure, typically varies over a narrow range determined by tissue metabolic needs. As a result, it is common to consider tissue oxygen and carbon dioxide partial pressures, along with water vapour pressure, as fixed. On the other hand, inert gases vary considerably.

Equilibration of arterial blood to changes in inspired helium or nitrogen partial pressures is sufficiently rapid that, over a time course relevant to decompression physiology, arterial blood can be considered in equilibrium with inspired gas. Blood-tissue exchange is typically described using a single-compartment kinetic model in which $P_{\text{tis}j}$ is each represented by a single, time-varying partial pressure, and arterial-tissue inert gas partial pressure difference ($P_a - P_{\text{tis}}$) declines mono-exponentially. Underlying this assumption of compartmental models is that, owing to rapid diffusion, equilibration of inert gas partial pressure gradients across the tissue region represented by the compartment is much faster than transport in and out of the compartment. The rate of change of compartmental partial pressure is given by:

$$\frac{dP_{\text{tis}}}{dt} = \frac{\left(P_{ai} - P_{\text{tis}}\right)}{T} - \frac{1}{V_{\text{tis}}\alpha_{\text{tis}}}\frac{d\left(P_{\text{bub}}V_{\text{bub}}\right)}{dt} \tag{25.5}$$

where the second term on the right-hand side accommodates transfer of gas between tissue and bubble and vanishes if there is no bubble.

Tissue perfusion is the principal factor determining equilibration of tissues with inspired inert gases, and therefore the time constant τ is usually defined y:

$$\tau = \frac{V_{\text{tis}}\alpha_{\text{tis}}}{Q_{\text{tis}}\alpha_{\text{blood}}} \tag{25.6}$$

where V_{tis} is tissue volume, Q_{tis} is tissue blood flow and $\alpha_{\text{tis}}/\alpha_{\text{blood}}$ is the tissue–blood gas partition coefficient. Diffusion-limited gas uptake may occur in poorly vascularised or avascular areas of the body that are relevant to DCS, such as articular cartilage and synovium [36] or the perilymph and endolymph spaces of the inner ear [37]. In decompression physiology it is common to characterise gas exchange using the half-time which is equal to $\ln(2)\tau$.

25.4.9 Decompression Algorithms

To minimise the risk of DCS, decompressions are conducted according to pressure/time/breathing gas decompression schedules that control the rate of decompression. In diving practice, the rate of decompression is typically controlled by interrupting ascent with 'decompression stops', by convention, at 10-fsw (3 msw) increments. Decompression proceeds by ascending to establish a gradient between alveolar and tissue inert gas partial pressures, and decompression stops are taken to allow washout of tissue inert gas limit tissue gas under conditions of limited supersaturation and consequent bubble formation. Successively shallower decompression stops may include switches to progressively higher oxygen fraction breathing gases (in accord with a maximum safe inspired oxygen partial pressure) to increase the alveolar–tissue inert gas partial pressure gradient. These decompression schedules are derived from decompression algorithms that exercise models of bubble formation and/or tissue gas uptake and washout.

Whereas early recreational divers were able to adopt readily available, military air decompression tables which were validated against databases of dives with known outcomes, no such trimix tables were available to early technical divers. Instead, technical divers implemented decompression algorithms which had, or in some cases were adapted to have, a structure that can accommodate the use of trimix breathing gases. The following is a brief account of the principal features of decompression algorithms available to technical divers. Decompression models and algorithms are more completely reviewed elsewhere [38].

25.4.9.1 Gas-Content Decompression Algorithms

Gas-content algorithms track the uptake and elimination of inert gas in notional tissue compartments with different gas kinetic properties and schedule decompression stops to limit the degree and duration of supersaturation. For instance, the most prevalent decompression algorithms are simply Eq. 25.5 (with no bubble) and specified maximum permissible supersaturations in the corresponding compartment. Since the tissue sites relevant to DCS are unknown, it is common to model collection of such compartments, each with a different half-time chosen to span some range thought to encompass all relevant tissues. This parallel compartment approach dates to Haldane and colleagues who produced the first decompression model and decompression schedules in the early twentieth century [39].

The earliest technical divers used custom trimix decompression tables prepared for them by R.W. Hamilton using a proprietary software (DCAP) implementation of the Tonawanda II decompression algorithm and the 11-F6 M-value matrix [40]. M-values specify the maximum permissible gas partial pressures at given decompression stop depths in the model compartments [41] and are a common method for specifying the maximum permissible supersaturation. Almost immediately thereafter, technical divers began implementing the Buhlmann ZH-L16 decompression algorithm, descriptions of which were readily available in the open scientific literature [42–44]. To accommodate trimix diving, both of these algorithms track helium and nitrogen independently in each compartment. In Tonawanda II, some compartments have a different half-time for helium than for nitrogen, and in ZH-L16 all compartments have nitrogen half-times that are 2.65-fold longer than helium half-times.

25.4.9.2 Bubble Decompression Algorithms

There are two general classes of bubble decompression algorithms, although they have overlapping aspects. One class calculates bubble size using equations of bubble growth and resolution due to gas diffusion between bubbles and the surrounding tissue [45, 46]. The second class of algorithms is much simpler, focusing on predictions of the number of bubbles that form during decompression [47]. These latter bubble-counting algorithms will be outlined here because they are widely available to technical divers [48, 49].

The varying permeability model (VPM) assumes a population of spherical gas nuclei, stabilised by a coating of surface-active agents, and a theoretical distribution of their radii that, along with Eq. 25.3, is used to calculate the number of gas nuclei activated into growing bubbles by the maximum supersaturation encountered during decompression [47]. In the simplest form of the VPM algorithm, decompression can be controlled by a predicted maximum allowed number of bubbles and, therefore, a maximum allowed supersaturation. Alternatively, the number of bubbles is converted to a simple index representing the number of bubbles and their growth by multiplying the number of bubbles by the time integral of supersaturation. The allowed supersaturation is that which, if sustained throughout the ascent, results in the target value of this bubble index. The parameters of the VPM algorithm were originally adjusted to give decompression times similar to existing military decompression tables [47].

25.4.9.3 Implementation and Availability of Decompression Algorithms for Technical Diving

Decompression algorithms may be used to produce a printed schedule (or 'table' of many schedules) that must be adhered to during the dive. There are several commercially available software implementations of the decompression algorithms that run on microcomputers (desktop decompression software) and which technical divers use to generate printed decompression schedules. Such software allows the user to tailor the decompression schedule to the depth/time/breathing gas plan intended to be used. Alternatively, decompression algorithms used by technical divers are also programmed into diver-carried dive computers.

Both Tonawanda II-11F6 and ZH-L16 are available in desktop decompression software, and ZH-L16 is also implemented in several dive computers used by technical divers. The ZH-L16 algorithm is probably the more widely used of the two gas-content algorithms, but the original parameterisation is rarely used by technical divers. Instead, ZH-L16 is modified by the end user, often using 'gradient factors'. In this usage, gradient refers, unconventionally (because it is not a gradient), to the difference between ambient pressure and an algorithm M-value [49, 50]. Supersaturation is limited to a fraction of the difference between ambient pressure and the original M-value. These fractions have come to be known as gradient factors [50]. Thus, if a diver elects to limit supersaturation to 80 % of the usual difference between ambient pressure and the M-value, this is referred as 'gradient factor 80' (GF 80). Typical proprietary implementations of the gradient factor method require the diver to select two gradient factors: the ‘low’ gradient factor modifies permitted supersaturation at the deepest decompression stop, and the ‘high’ controls supersaturation at the point of surfacing. The algorithm then interpolates a series of modified M-values in between these two user-specified points. If the first gradient factor is set less than 100 %, this forces deeper stops to limit supersaturation in the fast tissues early in the ascent, and setting the second gradient factor to less than 100 % will produce longer shallower stops to reduce supersaturation in the slower tissues in the latter phase of the ascent. A gradient factor higher than 100 % can be used to allow greater supersaturation and therefore shorter decompression stops than the original algorithm.

Several derivatives of VPM are available as desktop decompression software or programmed into dive computers. VPM-B is probably the most widely used variant [51]. Implementations of the VPM model for technical diving have a compartment structure similar to the ZH-L16 in which helium and nitrogen half-times differ in each compartment [51]. Most implementations have user-adjustable parameters that result in longer or shorter decompression times.

25.4.10 Technical Diving Decompression Schedules Are Not Validated

The decompression procedures promulgated by well-resourced organisations (e.g. the US Navy) are developed and validated in conjunction with human dive trials in which the conditions that influence the risk of decompression sickness (DCS) are well documented, the depth/time/breathing gas profiles are accurately recorded and the schedule prescribed by the algorithm and dive outcomes (typically DCS or not) are known. In the development phase, decompression algorithm parameters are found by prospective trial-and-error testing of dives that accurately follow the prescription of the decompression algorithm or by formal statistical fit of decompression models to existing databases of well-documented dives. The final decompression algorithm is validated by comparison to other man dives. The development and validation man dives are conducted under conditions similar to the intended use of the procedures. The final decompression schedules, either in the form of tables or as an algorithm programmed in a dive computer, are associated with rules that confine the routine use of the decompression algorithm to a domain in which it has been tested.

This approach is necessary because the bubble-tissue interactions that result in DCS have not been observed, and the tissues in which bubble injury manifests as DCS are sometimes uncertain. Consequently, the relevant gas uptake and washout, bubble formation and growth have not been measured, and these processes are represented with latent variables in decompression models. Furthermore, many factors known to influence the risk of DCS (such as diver work rate and thermal status) are not accommodated in the decompression algorithms. The decompression algorithms that result from manned development and validation are embodiments of the development data and are not intended for, and indeed do not extrapolate well to, all types of diving.

In contrast to the approach outline above, the decompression schedules used by technical divers have not been formally validated. First, the underlying decompression algorithms have not been developed and validated with the types of dives conducted by technical divers. Both Tonawanda II-11F6 and ZH-L16 were developed in association with laboratory testing, but few of these dives were relevant to technical diving. For instance, development of ZH-L16 included many man dives, although most were substantially shallower or deeper than the 60–90-m sea water (msw) typical of technical diving, and there were few trimix dives [44]. To our knowledge there is no formal validation of VPM-based technical diving decompression schedules. Second, technical divers rarely use schedules generated using the original parameterisations of these decompression algorithms but instead employ various end-user adjustments.

Early use of the original parameterisation of ZH-L16 was perceived to have an unacceptably high incidence of DCS. Indeed the only study documenting DCS incidence in technical diving, although very small, supports this notion [52]. Such perceptions lead to modifications such as gradient factors (see above). The original version of VPM has also largely been superseded by the more conservative derivative VPM-B, which itself is not a single algorithm but has user-adjustable parameter settings that make it more or less conservative. Other changes to decompression procedures have been driven by the belief that they will minimise time spent decompressing while at the same time maintaining an acceptably low risk of DCS (though none have been tested to prove this).

Some have suggested that the evolution of technical diving decompression procedures represent selection of improved practice through natural experiment. However, there clearly has been no community-wide experiment, most importantly because no data comparing different technical diving decompression procedures has been collected. The required data to evaluate decompression procedures are high-fidelity recordings of depth/time/breathing gas history and a measure of outcome (typically DCS or not). While there are some databases of depth/time recordings uploaded from dive computers which provide useful snapshots of relatively recent practice, these recordings are not accompanied by any outcome measure. Individuals or small groups have modified decompression practice based on their personal observations, and some of these changes have influenced changing fashions in the technical diving community. In this context it is worth exploring some areas where emerging evidence contradicts some assumptions of technical diving decompression practice.

25.4.10.1 Deep Stops

A characteristic of bubble algorithms is they typically prescribe deeper decompression stops than gas-content algorithms [47, 53]. In simple terms, bubble decompression algorithms favour deeper stops to limit supersaturation and thereby bubble formation early in the decompression, whereas traditional gas-content decompression algorithms favour a more rapid ascent to maximise the alveolar–tissue gradient of inert gas partial pressures to maximise tissue inert gas washout. Deep stops came to the attention of early technical divers in the form of empirical ‘Pyle stops’, a practice serendipitously developed by ichthyologist and technical diving pioneer Richard Pyle, arising from a requirement to vent the swim bladders of fish specimens collected at great depth before arriving at his first decompression stop. Pyle stops are one or more decompression stops performed deeper than the deepest stop prescribed by a gas-content algorithm and are followed by completing the longer decompression prescribed by the algorithm incorporating this extra time at depth [54]. There followed a strong trend towards the adoption of bubble algorithms and also for the use of manipulation of gradient factors to force gas-content algorithms to impose deep stops. Based largely on supportive anecdote, a widespread belief emerged among technical divers that deep-stop decompression schedules are more efficient than shallow-stop schedules. Efficiency, in this context, means that a schedule of the same or even shorter duration has a lower risk of DCS than some alternative schedule.

The few studies available at the time of adoption of deep stops by technical divers [53, 55] have been interpreted to support this notion. The earliest of these papers, an observational study of the practices of pearl divers in the Torres Strait of Australia [53], often cited as unqualified support for deep stops, is difficult to obtain and worth summarising here. These pearl divers performed air dives to depths up to 80 msw followed by empirically derived decompression schedules that had deeper stops and were somewhat shorter than accepted navy decompression schedules. Thirteen depth/time recordings were made of such dives, and these dives resulted in six cases of DCS (46 % incidence). The remaining data was a count of dives performed from four fishing vessels over a 2-month period, and these 468 man dives resulted in 31 reported cases of DCS (7 % incidence). It takes a certain cognitive dissonance to interpret these high incidences of DCS as supporting a deep-stop approach. The later of these papers used the then new method of ultrasonic VGE detection, and measurements were made during decompression from dry chamber dives (where chamber occupants are exposed to hyperbaric gas pressures). Fewer VGE were detected in five subjects whose decompression includes an additional decompression stop 10-fsw deeper than the schedules followed by other subjects [55]. The relevance of this observation to DCS is uncertain, because it is unknown if the difference in VGE grades persisted after surfacing, and it is the peak VGE grade, usually occurring 1–2 h after surfacing, that is (weakly) associated with the incidence of DCS [56]. Recently, however, evidence has been accumulating from comparative trials that shows deep stops are not more efficient, and possibly less efficient, than shallow stops. Several studies have shown no difference in VGE after deep-stop or shallow-stop decompression from air or trimix decompression dives [57–59], although it should be noted that these studies were underpowered. One large study has shown a higher incidence of DCS following deep stops than following shallow-stop decompression from air dives [60].

25.4.10.2 Multiple Inert Gases

In the Buhlmann ZH-L16 gas-content decompression model [43], each of the 16 compartments has a half-time for helium that is 2.65-fold shorter than the corresponding nitrogen half-time. These, or similar, compartment half-times are used in most decompression models available to technical divers. As a result of these compartment half-times, such decompression models will prescribe less decompression for a bounce dive conducted breathing nitrox or trimix than for a dive conducted breathing heliox because of a slower uptake of nitrogen than helium [44]. Faster uptake results in a deeper first stop and therefore longer decompression. Similarly, such decompression models will prescribe shorter decompressions if switching to nitrox breathing during decompression from a heliox or trimix dive [44].

It is not clear that the apparent differences in bounce diving decompression resulting from different inert gases are real. Direct measurement of helium and nitrogen exchange rates in faster exchanging tissues relevant to bounce diving indicates very similar rates of exchange for nitrogen and helium [14]. These latter data suggest heliox, nitrox and trimix decompression from bounce dives of the same depth and duration should be similar, and this is supported by comparison of nitrox and heliox no-stop dives [61]. Experiments comparing dives with heliox-to-air gas switching to dives with all heliox decompression are confounded by different decompression schedules and small numbers of dives, particularly on the schedules that provoked DCS [44]. On the other hand, a US Navy man trial indicates that a heliox-to-nitrox switch does not accelerate decompression [62].

25.4.11 Decompression Sickness in Technical Divers

The pathophysiology and manifestations of DCS in technical divers are the same as for any other diving communities. However, one manifestation of DCS that appears to be associated with very deep decompression dives is injury to the vestibulocochlear apparatus (inner-ear DCS), characterised by nausea, vertigo and hearing loss, often with no other manifestations. This is of particular concern to technical divers because symptoms characteristically onset during decompression and are life threatening for a SCUBA diver who must choose between the risk of drowning or omitting a substantial decompression obligation [37].

Inner-ear DCS during decompression from deep heliox dives characteristically follows switching to nitrox breathing gas (e.g. air) [63–65]. Symptoms of injury to the vestibulocochlear apparatus have occurred after breathing nitrogen-rich gas mixtures during deep heliox chamber dives, without any change in depth [66]. This latter finding is explained by a physiological model of the inner ear which indicates that following a switch from a helium-rich to a nitrogen-rich breathing mixture, transient supersaturation can develop in the vascularised membranous labyrinth without any change in depth, principally due to diffusion of helium from the endolymph and perilymph exceeding the counter-diffusion of nitrogen in the opposite direction [37]. This effect is opposite to the predictions of all decompression algorithms available to technical divers, in which a helium-to-nitrogen switch will result in a transient undersaturation, as noted in the preceding section.

The actual contribution of gas switches to inner-ear DCS during decompression from technical dives is uncertain. The inner-ear model [37] predicts substantial pre-existing supersaturation in the inner ear during decompression from such dives and that the counter-diffusion of gases following a helium-to-nitrogen mix gas switch makes only a small contribution to the total supersaturation at the depths where such switches are usually made.

Inner-ear DCS, without other symptoms, also occurs following relatively shallow air or nitrox dives, and among such cases there is a high prevalence of major right to left shunting of venous bubble contrast, demonstrated using transcranial Doppler sonography [67, 68]. This association suggests that inner-ear DCS might be caused by passage of arterialised venous bubbles into the labyrinthine artery. These divers frequently do not develop cerebral manifestations despite the fact that if bubbles reach the labyrinthine artery they must also distribute widely in the brain because the labyrinthine artery is usually a tiny branch of the much larger basilar artery. The selective vulnerability of the inner ear in this setting may relate to slower inert gas washout, and therefore more prolonged supersaturation, in the inner ear than the brain. Under these circumstances, small arterial bubbles reaching the inner ear are more likely to grow and cause symptoms than bubbles reaching the brain [69].

This mechanism may also be relevant to the onset of inner-ear DCS at depth during decompression, when inner-ear symptoms characteristically occur in technical diving. Thus, it is possible that arterialised VGE could reach the inner-ear microcirculation at a time during decompression when substantial supersaturation is predicted [37]. It may be coincidental that gas switches are often made at a time when the inner ear is supersaturated, or it may be that these bubbles can grow more quickly following a nitrogen-to-helium switch because of the greater flux of helium into the vascular tissue than removal of nitrogen, as previously described.

References

1. Mitchell SJ, Doolette DJ. Recreational technical diving part 1. An introduction to technical diving. Diving Hyperb Med. 2013;43:86–93.
2. Doolette DJ, Mitchell SJ. Recreational technical diving part 2. Decompression from deep technical dives. Diving Hyperb Med. 2013;43:96–104.
3. Molvaer O. Otorhinolaryngological aspects of diving. In: Brubakk AO, Neuman TS, editors. The physiology and medicine of diving. Edinburgh: Saunders; 2003. p. 227–64.
4. Neuman TS. Arterial gas embolism and pulmonary barotrauma. In: Brubakk AO, Neuman TS, editors. The physiology and medicine of diving. Edinburgh: Saunders; 2003. p. 557–77.
5. Vann RD, Hamilton RW. Central nervous system oxyen toxicity In: Vann RD, Mitchell SJ, Denoble PJ, Anthony TG, editors. Technical diving conference proceedings. Durham: Divers Alert Network; 2009. p. 38–66.
6. Bennett PB, Mitchell SJ. Nitrogen narcosis, oxygen narcosis, and the high pressure nervous syndrome. In: Vann RD, Mitchell SJ, Denoble PJ, Anthony TG, editors. Technical diving conference proceedings. Durham: Divers Alert Network; 2009. p. 67–98.
7. Francis TJR, Mitchell SJ. Pathophysiology of decompression sickness. In: Brubakk AO, Neuman TS, editors. The physiology and medicine of diving. Edinburgh: Saunders; 2003. p. 530–56.
8. Vann RD, Butler FK, Mitchell SJ, Moon RE. Decompression illness. Lancet. 2011;377:153–64.
9. Francis TJR, Mitchell SJ. Manifestations of decompression disorders. In: Brubakk AO, Neuman TS, editors. The physiology and medicine of diving. Edinburgh: Saunders; 2003. p. 578–99.
10. Richardson D. Training scuba divers: a fatality and risk analysis. In: Vann RD, Lang MA, editors. Recreational diving fatalities. Proceedings of the Divers Alert Network 2010 April 8–10 workshop. Durham: Divers Alert Network; 2011. p. 119–64.
11. Ladd G, Stepan V, Stevens L. The abacus project: establishing the risk of recreational scuba death and decompression illness. SPUMS J. 2002;32:124–8.
12. Fock AW. Analysis of closed-circuit rebreather deaths 1998–2010. Diving Hyperb Med. 2013;43:78–85.
13. Richardson D. Taking ‘tec’ to ‘rec’: the future of technical diving. SPUMS J. 2003;33:202–5.
14. Doolette DJ, Mitchell SJ. Hyperbaric conditions. Compr Physiol. 2011;1:163–201.
15. Warkander DE, Norfleet WT, Nagasawa GK, Lundgren CEG. Physiologically and subjectively acceptable breathing resistance in divers’ breathing gear. Undersea Biomed Res. 1992;19:427–45.
16. Wood LDH, Bryan AC. Effect of increased ambient pressure on flow volume curve of the lung. J Appl Physiol. 1969;27:4–8.
17. Hesser CM, Linnarsson D, Fagraeus L. Pulmonary mechanics and work of breathing at maximal

ventilation and raised air pressure. J Appl Physiol. 1981;50:747–53.

18. Lundgren CEG. Immersion effects. In: Lundgren CEG, Miller JN, editors. The lung at depth. New York: Marcel Decker; 1999. p. 91–128.
19. Koulouris NG, Valta P, Lavoie A, Corbeil C, Chasse M, Braidy J, Milic-Emili J. A simple method to detect expiratory flow limitation during spontaneous breathing. Eur Respir J. 1995;8:306–13.
20. Moon RE, Cherry AD, Stolp BW, Camporesi EM. Pulmonary gas exchange in diving. J Appl Physiol. 2009;106:668–77.
21. Poon CS. Ventilatory control in hypercapnia and exercise: optimization hypothesis. J Appl Physiol. 1987;62:2447–59.
22. Camporesi EM, Bosco G. Ventilation, gas exchange, and exercise under pressure. In: Brubakk AO, Neuman TS, editors. Bennett and Elliott's physiology and medicine of diving. 5th ed. Edinburgh: Saunders; 2003. p. 77–114.
23. Mummery HJ, Stolp BW, deL Dear G, Doar PO, Natoli MJ, Boso AE, Archibold JD, Hobbs GW, El-Moalem HE, Moon RE. Effects of age and exercise on physiological dead space during simulated dives at 2.8 atm abs. J Appl Physiol. 2003;94:507–17.
24. Mitchell SJ, Cronje F, Meintjes WAJ, Britz HC. Fatal respiratory failure during a technical rebreather dive at extreme pressure. Aviat Space Environ Med. 2007;78:81–6.
25. Harris R. Rebreathers: overcoming obstacles in exploration. In: Vann RD, Denoble PJ, Pollock NW, editors. Rebreather forum 3 proceedings. Durham: AAUS/DAN/PADI; 2014. p. 56–61.
26. Warkander DE, Norfleet WT, Nagasawa GK, Lundgren CE. CO2 retention with minimal symptoms but severe dysfunction during wet simulated dives to 6.8 atm abs. Undersea Biomed Res. 1990; 17:515–23.
27. Shykoff BE, Warkander DE. Exercise carbon dioxide (CO_2) retention with inhaled CO2 and breathing resistance. Undersea Hyperb Med. 2012;39:815–28.
28. Lambertsen CJ, Ewing JH, Kough RH, Gould R, Stroud MW. Oxygen toxicity. Arterial and internal jugular blood gas composition in man during inhalation of air, 100% O2 and 2% CO2 in O2 at 3.5 atmospheres ambient pressure. J Appl Physiol. 1955;8: 255–63.
29. Trytko B, Mitchell SJ. Extreme survival: a deep technical diving accident. SPUMS J. 2005;35:23–7.
30. Hemmingsen EA. Cavitation in gas-supersatured solutions. J Appl Phys. 1975;46:213–8.
31. Eckenhoff RG, Olstad CS, Carrod G. Human dose-response relationship for decompression and endogenous bubble formation. J Appl Physiol. 1990;69:914–8.
32. Weathersby PK, Homer LD, Flynn ET. Homogenous nucleation of gas bubbles in vivo. J Appl Physiol. 1982;53:940–6.
33. Evans A, Walder DN. Significance of gas micronuclei in the aetiology of decompression sickness. Nature. 1969;222:251–2.
34. McDonough PM, Hemmingsen EA. Bubble formation in crustaceans following decompression from hyperbaric gas exposure. J Appl Physiol. 1984;56:513–9.
35. Vann RD, Grimstad J, Nielsen CH. Evidence for gas nuclei in decompressed rats. Undersea Biomed Res. 1980;7:107–12.
36. Weathersby PK, Meyer P, Flynn ET, Homer LD, Survanshi S. Nitrogen gas exchange in the human knee. J Appl Physiol. 1986;61:1534–45.
37. Doolette DJ, Mitchell SJ. A biophysical basis for inner ear decompression sickness. J Appl Physiol. 2003;94:2145–50.
38. Tikuisis P, Gerth WA. Decompression theory. In: Brubakk AO, Neuman TS, editors. Bennett and Elliott's physiology and medicine and diving. 5th ed. Edinburgh: Saunders; 2003. p. 419–54.
39. Boycott AE, Damant GCC, Haldane JS. The prevention of compressed-air illness. J Hygiene (Lond). 1908;8:342–443.
40. Hamilton RW, Turner P. Decompression techniques based on special gas mixes for deep cave exploration [Abstract]. Undersea Biomed Res. 1988;15(Suppl):70.
41. Workman RD. Calculation of decompression schedules for nitrogen-oxygen and helium oxygen dives. Research Report. Washington, DC: Navy Experimental Diving Unit; 1965. Report No: 6–65.
42. Bühlmann AA. Experimentalle Grundlagen der risikoarmen Dekompression nach Überdruckexpositionen. Schweiz Med Wochenschr. 1982;112:48–59.
43. Bühlmann AA. Die Berechnung der risikoarmen Dekompression. Schweiz Med Wochenschr. 1988; 118:185–97.
44. Buhlmann AA. Decompression – decompression sickness. In: Michel GPt, editor. Berlin: Springer; 1984.(English translation of Dekompression – dekompressionkrankheit, first published 1983).
45. Gernhardt ML. Development and evaluation of a decompression stress index based on tissue bubble dynamics [Thesis]. Philadelphia: University of Pennsylvania; 1991.
46. Gerth WA, Vann RD. Probabilistic gas and bubble dynamics models of decompression sickness occurrence in air and N_2-O_2 diving. Undersea Hyperb Med. 1997;24:275–92.
47. Yount DE, Hoffman DC. On the use of a bubble formation model to calculate diving tables. Aviat Space Environ Med. 1986;57:149–56.
48. Yount DE, Maiken EB, Baker EC. Implications of the varying permeability model for reverse dive profiles. In: Lang MA, Lehner CE, editors. Proceedings of the reverse dive profiles workshop; 1999 Oct 29–30; Washington DC. Washington, DC: Smithsonian Institution; 2000. p. 29–60.
49. Wienke BR. Reduced gradient bubble model. Int J Biomed Comput. 1990;26:237–56.
50. Baker EC. Clearing up the confusion about "deep stops". Immersed. 1998;3:23–31.
51. Baker EC. Varying permeability model (VPM) decompression program in FORTRAN with Boyle's

law compensation algorithm (VPM-B) [Internet]. cited 20 Jan 2004. 2003. Available from URL: ftp://decompression.org/Baker.

52. Doolette DJ. Decompression practice and health outcome during a technical diving project. SPUMS J. 2004;34:189–95.
53. LeMessurier DH, Hills BA. Decompression sickness: a thermodynamic approach arising from a study of Torres Strait diving techniques. Hvalradet Skrifter. 1965;48:84.
54. Pyle RL. The importance of deep safety stops: rethinking ascent patterns from decompression dives. SPUMS J. 1997;27:112–5.
55. Neuman TS, Hall DA, Linaweaver PG. Gas phase separation during decompression in man: ultrasound monitoring. Undersea Biomed Res. 1976;3:121–30.
56. Nishi RY, Brubakk AO, Eftedal OS. Bubble detection. In: Brubakk AO, Neuman TS, editors. Bennett and Elliott's physiology and medicine of diving. 5th ed. Edinburgh: Saunders; 2003. p. 501–29.
57. Blatteau JE, Hugon M, Gardette B, Sainty JM, Galland FM. Bubble incidence after staged decompression from 50 or 60 msw: effect of adding deep stops. Aviat Space Environ Med. 2005;76:490–2.
58. Blatteau JE, Hugon M, Gardette B. Deeps stops during decompression from 50 to 100 msw didn't reduce bubble formation in man. In: Bennett PB, Wienke BR, Mitchell SJ, editors. Decompression and the deep stop. Proceedings of the Undersea and Hyperbaric Medical Society Workshop; 2008 Jun 24–25; Salt Lake City (UT). Durham: Undersea and Hyperbaric Medical Society; 2009. p. 195–206.
59. Gutvik CR, Dunford RG, Dujic Z, Brubakk AO. Parameter estimation of the Copernicus decompression model with venous gas emboli in human divers. Med Biol Eng Comput. 2010;48:625–36.
60. Doolette DJ, Gerth WA, Gault KA. Redistribution of decompression stop time from shallow to deep stops increases incidence of decompression sickness in air decompression dives. Technical Report. Panama City: Navy Experimental Diving Unit; 2011 Report No: NEDU TR 11-06.
61. Hamilton RW, Thalmann ED, Flynn ET, Temple DJ. No-stop 60 fsw wet and dry dives using air, heliox, and oxygen-nitrogen mixtures. Data report on projects 88-06 and 88-06A. Technical Report. Silver Spring: Naval Medical Research Center; 2002. Report No: 2002-002.
62. Survanshi SS, Parker EC, Gummin DD, Flynn ET, Toner CB, Temple DJ, et al. Human decompression trial with 1.3 ATA oxygen in helium. Technical Report. Bethesda: Naval Medical Research Institute; 1998. Report No: 98-09. 80 p.
63. Farmer JC, Thomas WG, Youngblood DG, Bennett PB. Inner ear decompression sickness. Laryngoscope. 1976;86:1315–27.
64. Bennett PB, Vann RD, Roby J, Youngblood D. Theory and development of subsaturation decompression procedures for depths in excess of 400 feet. In: Shilling CW, Beckett MW, editors. Underwater Physiology VI. Proceedings of the Proceedings of the 6th Symposium on Underwater Physiology. Bethesda: Federation of American Societies for Experimental Biology; 1978. p. 367–81.
65. Bühlmann AA, Gehring H. Inner ear disorders resulting from inadequate decompression "vertigo bends". In: Lambertsen CJ, editor. Underwater Physiology V. Proceedings of the Proceedings of the 5th Symposium on Underwater Physiology. Bethesda: FASEB; 1976. p. 341–7.
66. Lambertsen CJ, Idicula J. A new gas lesion syndrome in man, induced by "isobaric gas counterdiffusion". J Appl Physiol. 1975;39:434–43.
67. Cantais E, Louge P, Suppini A, Foster PP, Palmier B. Right-to-left shunt and risk of decompression illness with cochleovestibular and cerebral symptoms in divers: case control study in 101 consecutive dive accidents. Crit Care Med. 2003;31:84–8.
68. Klingmann C. Inner ear decompression sickness in compressed-air diving. Undersea Hyperb Med. 2012;39:589–94.
69. Mitchell SJ, Doolette DJ. Selective vulnerability of the inner ear to decompression sickness in divers with right to left shunt: the role of tissue gas supersaturation. J Appl Physiol. 2009;106:298–301.

Part III

Prevention, Training and Rehabilitation

26

Training and Injury Prevention Strategies in Extreme Sports

Maggie Henjum and Justin Dudley

26.1 Introduction

Athletes who participate in extreme sports accept a certain level of risk of injury. These injuries range in severity from minor abrasions and overuse injuries to fatal and catastrophic. An individual athlete determines an acceptable level of risk within a respective sport. As clinicians, our roles range from emergency medical care in the field or a clinic setting to preseason prevention programs and training. This chapter will focus on the injury prevention and training.

In order to develop effective prevention strategies, it is important to understand the demands of a sport, beginning with what risk factors are modifiable. Then, one should differentiate between intrinsic and extrinsic factors. Finally, one should develop a strategy to minimize unacceptable risk levels. It is beyond the scope of this chapter to discuss all extreme sports, but the principles for developing prevention strategies discussed here can be successfully applied to additional sports not otherwise covered in this chapter.

From the perspective of evaluating risk for any sport, identifying the factors associated with injuries is one of the initial steps in the process of injury prevention [1]. Injuries often result from a complex interaction of multiple factors. Addressing just one factor may be insufficient when attempting to develop long-term intervention programs. When preparing an athlete for their respective sports, we need to first differentiate between intrinsic and extrinsic factors. Intrinsic factors include psychological factors, skill level, age, previous injury, crash behavior, fatigue, genetics, anatomical and hormonal variances, and physical fitness (including strength and endurance, aerobic/anaerobic conditioning, flexibility, coordination) [2]. Extrinsic factors include equipment, weather, terrain, speed, and other participants [2].

Understanding these demands of each sport provides the foundation to train or adjust the modifiable risk factors to decrease the risk of injury. Once this has been accomplished, prevention strategies can be formulated and investigated through randomized controlled trials. We will focus on modifiable intrinsic factors, specifically physical attributes and fatigue. Figure 26.1 is an example of interactions between intrinsic and extrinsic factors and their relationship to injury (Fig. 26.1).

When evaluating risk in the preseason, ideally a sport-specific functional test will be utilized to obtain data, tease out areas of weakness, and match a specific training program precisely to the task the athlete requires. The best strength programs are

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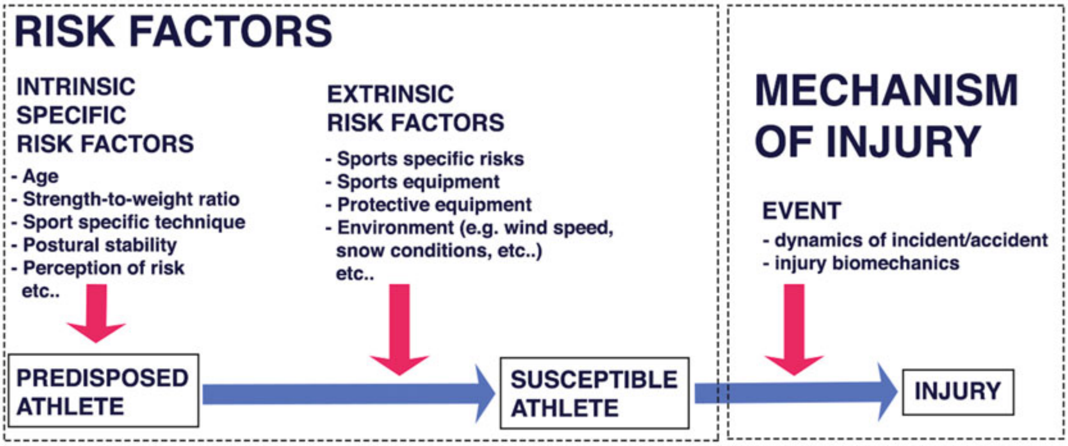

Fig. 26.1 A theoretical model for injury causation in extreme sports. Adapted from [2]

those that balance impairment management and the continued training of an athlete's strengths. Current research states that the best time to implement injury prevention programs is during off-season or preseason, with continued maintenance during the season [3].

The demands vary from sport to sport. For example, backcountry skiing and snowboarding will have obvious varied requirements than mountaineering or climbing. Due to this, preventative measures will be broken down into the following: skiing/snowboarding, climbing/mountaineering, and mountain biking.

26.2 Backcountry Skiing and Snowboarding

Skiing and snowboarding continue to be the most popular winter recreational activities. An estimated 8.2 million people participated in snowboarding and 11.5 million in skiing in 2010 [4]. Although injury rates fluctuate, snowboarding injury rates seem to currently be slightly higher [4]. The demands of skiing vary slightly between alpine racing, recreational resort skiing/snowboarding, and backcountry touring.

As there is not significant high-level evidence for epidemiology of backcountry and side country skier injuries, correlations will be drawn from alpine skiing with special considerations of modifiable intrinsic factors unique to backcountry participation. For example, if an injury is sustained in the backcountry, medical care access is limited. Therefore, even a minor knee sprain can become a life-threatening injury due to terrain, weather, and ability to self-extricate from the location. As a result, injury prevention and optimal physical fitness is an imperative component to safety in the backcountry.

Aerobic and anaerobic conditioning should be primary consideration to decrease fatigability of the athlete. The aerobic and anaerobic training should be specifically tailored for the participant and their demands. Athletes in slope style or terrain park competitions will require less aerobic capacity and more anaerobic training than a ski mountaineer ("SkiMo") racer. Skiing and snowboarding require muscle groups to act statically and dynamically based on athlete positioning within the sport. In general, these muscle groups include trunk rotation, trunk lateral flexion, hip extension, hip abduction, hip external rotators, and hip adductors [5].

Preseason workouts should isolate these areas of weakness, especially after fatigue-based training to tease out possible failure of form or control. Fatigue is known to have a negative impact on balance control while physical fitness has an effect on reaction time during exercise [6]. Depending on how the athlete reaches the top of the slope to be skied ascent needs to be considered. Backcountry skiers often spend numerous hours climbing the slopes they expect to ski. This increases the risk of fatigue for the actual ski run(s), thus, risk for falls increases linearly. It is essential that these athletes have a strong aerobic capacity, as well as a training program that focuses on slow steady climbing to utilize fat oxidation rather than depleting muscle glycogen stores. A superior cardiovascular base fitness, paired with appropriate clothing and pacing, helps to minimize excessive sweating during the climb, and this decreases risk of hypothermia and form fatigue or instability in backcountry winter travelers.

Although literature is relatively limited in backcountry injuries, alpine racers present numerous studies evaluating physical fitness and its correlative factors to injury rates [7]. The knee is the most common area of injury in skiers (the MCL and ACL specifically). When developing specific training programs for different demographics, it is important to compare incidence of injury between skiers and snowboarders. Wrist injuries accounted for 27.6 % of snowboarding injuries and only 2.8 % of skiing injuries, and ACL composed 1.7 % of snowboard injuries compared to 17.2 % of skiing injuries [4]. Shoulder injuries are not a primary focus of this chapter as most shoulder injuries are secondary to trauma or falls rather than poor mechanics or overuse; it is important to note that 4–11 % of skiing injuries and 8–16 % of snowboarding injuries are about the shoulder complex [8]. Thus, extrinsic factors of equipment and protective gear may be of interest when considering the shoulder, as well as intrinsic factors including proper fall education, and prevention of falls.

Most injuries tend to occur when a skier is off-balance. Primarily falls transpire when the athlete's weight is on the tail of the ski, attempting to recover from this backseat position or combating an imminent fall [9]. As a result, kinematics and control of lower extremities in dynamic situations are extremely important for prevention [2]. Considering frequency of injuries in above stated situation, sagittal plane control, in specific, posterior to anterior weight shifting comfort, and control are crucial.

Poor trunk, hip abductor, and hip external rotator strength and control have been widely accepted as a risk factor for ACL injuries [10]. Raschner and colleagues performed a 10-year longitudinal study looking at ACL injuries in young competitive ski racers and specifically found that trunk strength is a predominant critical factor for ACL injuries. Thus, dynamic trunk control in various body positions will be an essential component of the injury prevention training [1].

Moreover, double leg exercise versus single need to be considered based on type of activity. For example, telemark skiing may require more single leg control, versus snowboarding, which will require more double leg consideration in a prevention program. Although no single program is appropriate for everyone, the principles of progression can be applied across athletes. The general equation of progression takes the athlete from controlled exercises on stable surfaces, to more dynamic surfaces, to rotational forces for unpredicted direction changes, and then lastly to the above components without visual dependency. This is conducted, all while maintaining optimal posturing and stability. Within each phase of strength training and control, the athlete will be progressed from double limb support to single limb support, controlling if appropriate to the relevant sport.

Finally, when discussing injury prevention in backcountry skiing, it is essential to briefly discuss the role avalanche injury and death play on this population. In a 21-year review of avalanche fatalities between 1984 and 2005, backcountry skiers had the greatest number of deaths when compared to other backcountry travelers. Asphyxia caused ~75 % of deaths while trauma accounted for 24 % [11]. Experienced 36-year-old male backcountry travelers accounted for the highest demographic killed by avalanches, and the majority of these individuals were equipped with backcountry avalanche recovery equipment, including beacon, probe, and shovel [12]. Continued emphasis on understanding and avoiding avalanche prone slopes is an essential part of an injury prevention program for backcountry travelers.

26.2.1 Conclusion

Extreme skiing and snowboarding (both in bounds and in the backcountry) present a moderate risk of injury to athletes participating in these activities. Through understanding the modifiable injury risks, a preseason training program can be developed to decrease these injuries. Programs should focus on aerobic and anaerobic conditioning, static positioning for endurance, balance, hip and trunk strength, and dynamic control through various positions in order to decrease the theoretical risk of injury within these athletes. As discussed previously, a preseason training program will not guarantee injury prevention as high-level skiing and snowboarding deal with numerous extrinsic variables like terrain, conditions, and equipment, but it will allow the athlete to improve physical conditioning, balance, and muscular control prior to the season. Studies need to be performed to evaluate the efficacy of these preseason training programs in this population of athletes.

26.3 Mountain Biking

Mountain biking is an evolving sport that requires the negotiation of rough terrain and obstacles at relatively fast speeds. It is estimated that between 2006 and 2012, 17 % of Americans over the age of 6 mountain bike [13]. Due to the growing popularity and the physically demanding nature of mountain biking, there has been an overall increase in injuries. The most common injuries (60–75 %) are soft-tissue abrasions, lacerations, and contusions and are considered minor in nature [14]. However, the risk of serious injury including fracture, spinal injury, and even death are present. The majority of injuries sustained in this sport are due to falls [15], and thus, the majority of research available is focused on traumatic injuries. A few articles have looked at overuse syndromes in mountain bike athletes.

A 2008 review states this in terms of prevention "that riders should be well trained, ride within the level of their capability, learn to dismount safely and use a well-maintained bike without handlebar ends. They should also wear helmets with facial protection, padded gloves and shorts, use cushioned seats and shin protection" [16]. Although prevention literature is far less prevalent than traumatic literature, it has been established that anywhere from 50 to 90 % of participants have pain from overuse in the following areas: lumbar spine, buttocks, and knees [17, 18].

Overall, it is estimated that overuse injuries are less common in mountain bikers when compared to road cyclists. This is likely due to geometry of a mountain bike being more upright resulting in a more natural position and less hip and lumbar flexion. Also, due to the nature of mountain biking, riders are often changing positions as they attempt to negotiate rocks, roots, drops, and other obstacles on the course. Despite these differences, overuse injuries continue to be a reality for mountain bikers.

The most common site of overuse is the knee, with a leading diagnosis of patellofemoral pain syndrome (PFPS) from abnormal stress at the patellofemoral joint resultant of poor biomechanics of the knee joint [19]. PFPS can be influenced by local factors including tight quadriceps, decreased vastus medialis obliquus contraction strength and timing, tight iliotibial band, or patella alta/baja. Proximal factors also have a significant role in PFPS. Hip strength and control, particularly the hip abductors and external rotators, control the position of the femur under the patella. Abnormal movement in the frontal and transverse planes at the hip joint results in decreased contact area between femur and patella and thus increasing the stress in the tissue and increasing risk of pain or injury [20]. The knee joint is essentially a two-dimensional joint sandwiched between two three-dimensional joints, the hip and ankle. The knee is often the site of pain, but the cause is often due to dysfunction at one of the two three-dimensional joints. Early onset of fatigue, poor strength, or inappropriate length of structures around these joints can all perpetuate increased stress at the knee.

Iliotibial band (ITB) syndrome is another common overuse injury noted in mountain bikers. ITB syndrome presents as intense pain in the lateral aspect of the knee and is self-reported to decrease pedal stroke power. Because the ITB crosses the lateral aspects of the hip and knee, similar to PFPS, excessive transverse and frontal plane motions can affect the lower extremity strain.

Relationships between fatigue and change in cycling mechanics and biomechanics are very prevalent in this population [19]. Dingwell et al. demonstrate that when an athlete is exhausted on a stationary bike, the trunk, hip, knee, and ankle kinematics change [21]. Abt et al. demonstrate that following exercises that fatigue the core will also result in altered cycling mechanics at the knee and ankle [22]. Based on these findings, it stands to reason that athletes with poor lower extremity and core strength and endurance will likely present with altered cycling mechanics increasing the risk of injury.

Additional research has shown that women are 1.94 times more likely to be injured and 4.17 times more likely to sustain a fracture than males of similar skill level. Males make up 80 % of mountain bike injuries due to their increased numbers in the sport, and when this variable is controlled and compared to women, women are almost twice as likely to be injured across skill levels [23]. The most common reason reported by women for crashing is losing control of their bikes [23]. The demands of mountain biking requires significant core and upper body strength in order to control the bike in rough terrain and keep the athlete's body on the bike. Less upper body strength reduces one's ability to control the bike over difficult terrain [24]. It is proposed that a specific trunk and upper body-strengthening program may decrease the incidence of losing control of the bike within the female population.

Low back pain is another common overuse complaint within the mountain biking community. The constant and unnatural forward lean position on the bike, combined with the repetitive motion and mircotrauma, increases the strain on the low back and increases the risk of overuse injury. Lastly, lumbar spine pathology is thought to occur via mechanisms such as spinal extensor hyperactivity, elongation stress on noncontractile structures, or decreased movement of fluid in lumbar disks [13]. Core strength and endurance can help to maintain a neutral spine and active intrinsic shock absorption throughout the region decreasing strain on the noncontractile structures.

Addressing the aforementioned intrinsic factors like flexibility and strength will help to decrease overuse injury risk, but without a proper bike fit, the efforts will likely fall short of alleviating pain. Fitting a bike to the athlete is a specific skill that is beyond the scope of this chapter but needs to be considered when working with patients in this demographic. Seat height, forward/back position of the seat, head tube angle, and handlebar attachments all have been shown to contribute to overuse injury in mountain bike athletes [25].

26.3.1 Conclusion

Over 50 % of mountain bike athletes complain of overuse type injuries with the butt, spine, and knees being the most common area of pain. Despite this high number of overuse injuries, majority of research continues to be on traumatic injuries. However, there is growing research to support the use of preseason strengthening, aerobic capacity, and dynamic control in the use of injury prevention. Further research in this area is warranted to determine the effectiveness of these programs. Mountain biking requires a significant amount of hip, quadriceps, and hamstring strength to propel the bike, as well as core and upper extremity strength to control the position of the rider on the bike. Thus, a training program should focus on lower extremity strength and endurance, core static and dynamic control, and upper extremity strengthening programming, particularly for females.

26.4 Mountaineering and Climbing

When discussing injury risk and prevention for this population, it is important to understand the differences between traditional mountaineering, alpine climbing, tradition (trad) climbing, and sport climbing. We will focus on alpine climbing and sport climbing since those are currently the two areas with the greatest growth in participation and tend to encompass components of the other styles.

26.4.1 Alpine Climbing

Alpine climbing is a sport that involves movement in a mountain environment over steep terrain and encompasses the various disciplines of rock and ice climbing, mountaineering, and mountain traveling [26]. These climbs often require long approaches to the climbing pitch, followed by steep technical climbing of rock and ice often using rope protection. Because alpine climbing blends the demands of the various climbing disciplines, the climber is placed at risk for a wide variety of injuries. Similar to the other sports discussed in this chapter, falls account for the majority of injuries, particularly those injuries which are considered serious or result in death in alpine climbers. Thus, strategies to minimize the risk of falling (placing proper protection, climbing within abilities, wearing protective equipment) are an essential component to injury prevention in these athletes. Most studies use data collected from hospital or search and rescue efforts and thus miss many of the minor injuries for which athletes evacuated or treated themselves [26]. However, due to the nature of alpine climbing, these athletes are also at risk of overuse injuries of both upper and lower extremities.

There is very limited data available specifically for injuries sustained on approach to alpine climbs, but we can extrapolate from research on common injuries in long-distance runners and hikers. Increased loads of carrying a pack, as well as traveling over uneven terrain on the approach, increase the strain on the knee and other tissues of the lower extremities. Long-distance hikers and runners frequently present with complains of ITB syndrome and patellofemoral pain syndrome (see above for description of pain and causes) [27]. Downhill hiking, plus the added weight of a pack, increases the demands to resist aberrant motion in the frontal and transverse planes as well as increasing the patellofemoral compression forces. Hiking downhill a 40° slope yields a three to four times greater patellofemoral joint compressive force compared to level walking [28]. Utilizing trekking poles during the descent has been shown to reduce compressive and shear forces at the knee joint [29].

Once on the climb, the injury risks shift slightly and become more similar to those seen in trad and sport climbers, and prevention of falls becomes more important. Because of the forces that climbers generate when propelling themselves up a steep terrain, chronic injuries of upper and lower extremities are present. Most of the upper extremity injuries involve the hand and wrist. Finger flexor tendon injuries and flexor tendon pulley injuries are predominant and can range from minor strains to complete rupture. The section on sport climbing will discuss this in further detail. However, it is important to note the major difference between sport climbing and alpine climbing; because sport climbing often uses fixed anchors, athletes will repeat the same move multiple times, while alpine climbers are placing their own protection and climbing over greater distances, and thus, the overuse finger injuries more often occur in training with alpine climbers.

Certain techniques used when climbing steep snow and ice may place alpine climbers at risk of lower extremity injury. The “French” technique when using crampons for climbing is often used for climbing moderately steep snow or ice. This technique attempts to keep all points of the crampons in contact with the slope through inverting and everting the ankles [27]. As the steepness of the slope increases, climbers switch to “front pointing” where the climbers’ weight is held on the front two points of crampons. This style of kicking the toe into the slope increases incidence of toe and foot injuries, as well as potential of Achilles tendonitis. Therefore, good ankle strength, stability, and proprioception are important components of a training program for this style of climbing.

Finally, because alpine climbers are required to spend many hours exerting significant amounts of energy, it is imperative that a training program for these athletes includes aerobic training. As noted previously, fatigue increases the risk of injury secondary to decreased reaction time and coordination. In addition, exertional fatigue has been linked to increased risk of hypothermia in cold weather environments.

26.4.2 Sport Climbing

Sport climbing often involves single pitch routes of high difficulty utilizing permanently placed belay points. This protection allows sport climbers to continue to push their abilities climbing more and more difficult routes, overhanging routes, and attempting a specific move within a route repeatedly. In contrast to traditional climbing in which the lower extremities support most of the body weight, sport climbers rely heavily on their upper extremities to do most of the work on difficult routes [30]. Because maximal power and endurance is required of the upper extremities, they are the major site of injury and overuse syndrome and require specific training programs. These injuries primarily involve the more slowly adapting tissues – ligaments, tendons, and joint capsules – rather than the more rapidly adapting muscle tissue [30].

About 75 % of sport climbers eventually suffer upper extremity overuse syndromes and injuries, with 60 % of the injuries occurring in the fingers and wrist, primarily in the third and fourth digit [31, 32]. Due to the small holds often utilized during sport climbing, a crimping or crimp grip is utilized. A crimp grip consists of hyperflexion of PIP and hyperextension of DIP. This can result in up to a 15° fixed flexion deformity of the PIP and should be prevented by regular active stretching following each training and competition that the crimp grip is used [30]. Tendon sheath and pulley injuries are other common "acute on chronic" injuries noted within sport climbers. The crimp grip position produces very high forces on the A2 pulley and therefore is the predominant site of pulley injury [30]. The range of motion, coordination, and power of the hand can be improved by the use of a number of commercial devices designed specifically for this purpose.

Elbow and shoulder injuries are less common than wrist and hand injuries but continue to be prevalent in sport climbers. Basic position of the upper extremity during sport climbing is typically the shoulder in 80–180° of elevation (in a position between abduction and scaption), forearm pronated, wrist extended in slight ulnar deviation, and fingers flexed or in crimp grip. Sport climbers present with four primary diagnoses at the elbow, medial and lateral epicondylalgia, anterior elbow pain (climber's elbow), and tricep tendinopathy, as well as shoulder impingement at the glenohumeral joint [30]. A growing body of research has shown a strong correlation between shoulder strength and function and the reduction of elbow pathology [33, 34]. Thus, strong musculature around the shoulder complex in a variety of overhead positions is needed for the whole upper kinetic chain. Because of the pulling motion in an abducted and/or overhead position, the humeral head will have a tendency toward superior migration increasing secondary impingement in the shoulder complex. Strong scapular stabilizers allow for a mobile, yet stable, platform for the rotator cuff to function in order to counteract this superior migration. Training of the scapula stabilizers and rotator cuff in end-range overhead positions is important when developing upper extremity injury prevention and training programs for sport climbers.

26.4.3 Conclusion

Understanding of the demands and differences between athletes within the various climbing disciplines is needed in order to develop effective injury prevention and training strategies. Training for alpine climbers should focus on aerobic endurance, ankle stability/proprioception, hip strength for frontal and transverse plane motion, and upper extremity strength and endurance for vertical pitches. Sport climbers need a more specific program targeting hand strength and coordination, wrist flexors, extensors, as well as scapula and rotator cuff strengthening and function in or near end-range overhead positions. In sport climbers, stretching and strengthening programs should not only focus on the climbing agonist muscles (flexors) but also the antagonist muscles (extensors) in order to minimize the risk of overuse upper extremity injuries. Further research will be helpful to examine the efficacy of these injury prevention training programs.

The following exercises are examples with the objective of progressing functional strength to challenging dynamic situations while emphasizing form, control, and stability to decrease injuries. These can be applied to backcountry skiing and mountain biking; second section with similar objectives are applied to the mountain climber for upper extremity stability.

Practitioner is advised to evaluate the following two common positional errors: genu valgus and poor posterior weight shifting (not all inclusive) (Fig. 26.2).

Fig. 26.2 (**a**) R knee genu valgus; (**b**) Poor posterior weight shift increasing knee stress

26.5 Functional Lower Extremity Strengthening

Fig. 26.3 Squatting for anterior to posterior weight shifting; primary objectives: strength and control

Fig. 26.4 Step-ups with weight; primary objective: strength

Fig. 26.5 Explosive floor to box retro step-ups; primary objectives: strength, control, and explosiveness

26.6 Functional Lower Extremity Strength Progression Including Dynamic Component and/or Stability

Fig. 26.6 Squatting push backs for leading leg control and rear leg strength and stability; primary objective: endurance, control, and stability

Fig. 26.7 Single-leg squatting on unstable surface; primary objectives: strength, control, and stability

Fig. 26.9 BOSU lunges; primary objectives: strengthening, control, and stability

Fig. 26.8 Sustained squatting on BOSU ball "skiers"; primary objectives: endurance, control, and stability

Fig. 26.10 Four-way hip strengthening on foam pad; primary objectives: strengthening, control, and stability

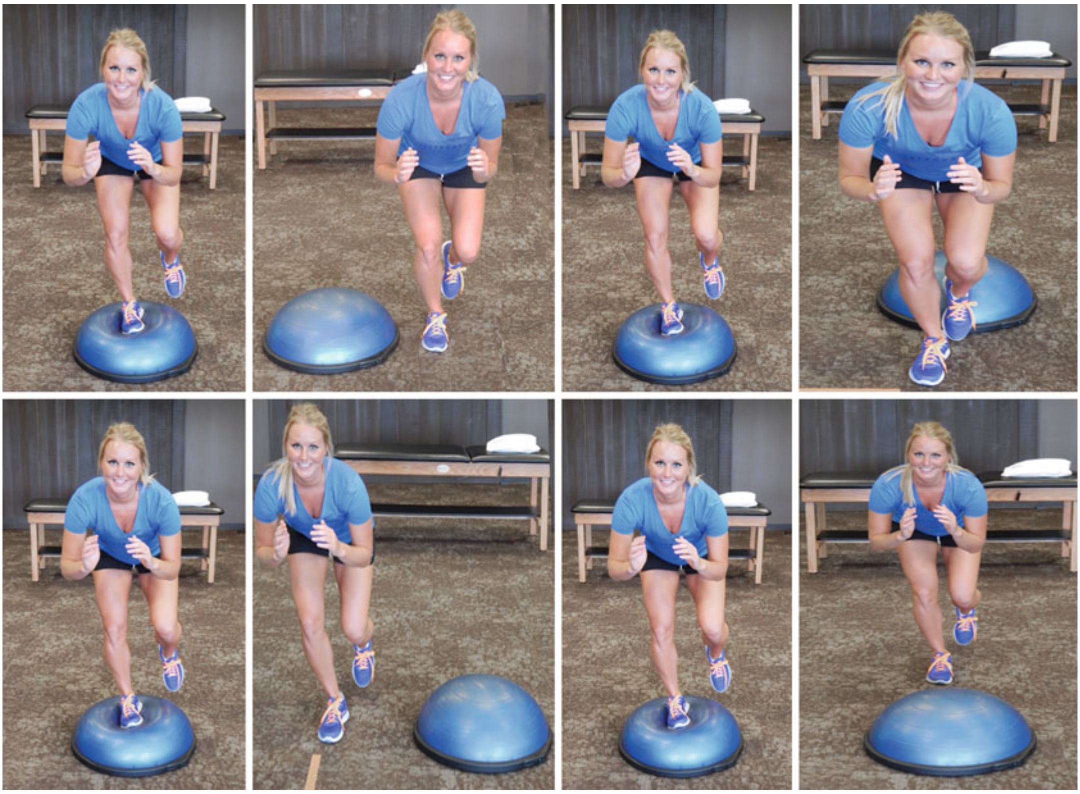

Fig. 26.11 Four-way jumping on and off BOSU ball; primary objectives: strength, endurance, control, and stability

26.7 Functional Strength with Stability, Change of Direction, and Upper Extremity Involvement to Challenge Dynamic Requirements of Extreme Sport Athletes

Fig. 26.12 Jumping double leg off of a box with 90° turns (progression single leg below); primary objectives: control and stability

Fig. 26.13 Single-leg squatting on BOSU ball with upper extremity perturbation of PNF strengthening; primary objectives: endurance, control, and stability

26.8 Agility Exercises to Challenge Quick Aerobic Conditioning and Control

Fig. 26.14 Quick jumping on and off of a box with single leg; primary objectives: endurance, control, stability, and agility

Fig. 26.15 Ladder drills; primary objectives: endurance, control, and agility

26.9 Upper Extremity Dynamic Strengthening

Fig. 26.16 Upper extremity strengthening (D2 PNF); primary objectives: strength, control, and stability

Fig. 26.17 Upper extremity strengthening on single leg (D2 PNF); primary objectives: strength, control, and stability

References

1. Raschner C, Platzer HP, Patterson C, Werner I, Huber R, Hildebrandt C. The relationship between ACL injuries and physical fitness in young competitive ski racers: a 10-year longitudinal study. Br J Sports Med. 2012;46:1065–71.
2. Sporri J, Kroll J, Amesberger G, Blake O, Muller E. Perceived key injury risk factors in World Cup alpine ski racing – an explorative qualitative study with expert stakeholders. Br J Sports Med. 2012;46:1059–64.
3. Steffen K, Andersen TE, Krosshaug T, et al. ECSS position statement 2009: prevention of acute sports injuries. Eur J Sport Sci. 2010;10(4):223–36.
4. Kim S, Endres NK, Johnson R, Ettlinger CF, Shealy JE. Snowboarding injuries: trends over time and comparisons with alpine skiing injuries. Am J Sports Med. 2012;40:4.
5. Morrissey MC, Seto JL, Clive BE, Kerlan RK. Conditioning for skiing and ski injury prevention. J Orthop Sports Phys Ther. 1987;8:428–37.
6. Simoneau M, Begin F, Teasdale N. The effects of moderate fatigue on dynamic balance control and attentional demands. J Neuroeng Rehabil. 2006;3:22.
7. Shealy JE, Sundman PD. Snowboarding injuries on alpine slopes: in seventh international symposium. Philadelphia: American Society for Testing and Materials; 1989. p. 75–81.
8. McCall D, Safran MR. Injuries about the shoulder in skiing and snowboarding. Br J Sports Med. 2009;43(13):987–92.
9. Tips for knee-friendly skiing: Vermont Ski safety website. http://www.vermontskisafety.com/knee-friendly.php. Published 2010. Accessed on 12 Aug 2014.
10. Myer GD, Ford KR, Khoury J, Succop P, Hewett TE. Biomechanics laboratory-based prediction algorithm to identify female athletes with high knee loads that increase risk of ACL injury. Br J Sports Med. 2011;45:245–52.
11. Boyd J, Haegeli P, Abu-Laban R, Shuster M, Butt J. Patterns of death among avalanche fatalities: a 21-year review. Can Med Assoc J. 2009;180:5.

12. Tough SC, Butt JC. A review of 19 fatal injuries associated with backcountry skiing. Am J Forensic Med Pathol. 1993;14(1):17–21.
13. Lebec MT, Cook K, Baungartel D. Overouse injuries associated with mountain biking: single-speed riding a predisposing factor? Sports. 2014;2:1–13.
14. Aleman K, Meyers M. Mountain biking injuries: an update. Sports Med. 2010;40:77–90.
15. Nelson NG, McKenzie B. Mountain biking-related injuries treated in emergency room departments in the United States: 1994-2007. Am J Sports Med. 2011; 39:2.
16. Carmont MR. Mountain biking injuries: a review. Br Med Bull. 2008;85:101–12.
17. Dingerkus M, Martinek V, Kolzow I, Imhoff A. Veretzungen und uberlastungsshcaden beim mountainkiken. Dtsch Z Sportmed. 1998;49:242–4.
18. Sabeti-Aschraf M, Serek M, Geisler M, Schmdt M, Pachtner T, Oschner A, Funovics P, Graf A. Overuse injuries correlated to the mountain bike's adjustment: a prospective field study. Open Sports Sci J. 2010;3: 1–6.
19. Frobose I, Lucker B, Wittmann K. Overuse symptoms in mountainbikers: a study with an empirical questionnaire. Dtsch Sporthochsch Koln. 2001;52: 311–5.
20. Powers C. The influence of abnormal hip mechanics on knee injury: a biomechanical perspective. J Orthop Sports Phys Ther. 2010;40:2.
21. Dingwell JB, Joubert JE, Diefenthaeler F, Trinity JD. Changes in muscle activity and kinematics of highly trained cyclists during fatigue. IEEE Trans Biomed Eng. 2010;55:2666–74.
22. Abt J, Smoliga J, Brick M, Jolly J, Lephart S, Fu F. Relationship between cycling mechanics and core stability. J Strength Cond Res. 2007;21:1300–4.
23. Kronisch RL, Pfeiffer RP, Chow TK, et al. Gender differences in acute mountain bike racing injuries. Clin J Sport Med. 2012;12:158–64.
24. Kronisch RL, Pfeiffer RP. Mountain biking injuries. Sports Med. 2002;32:523–37.
25. Asplund C, St Pierre P. Knee pain and bicycling: fitting concepts for clinicians. Phys Sportsmed. 2004;32:22–30.
26. Smith L. Alpine climbing: injuries and illness. Phys Med Rehabil Clin N Am. 2006;17:633–44.
27. Allen DJ. Treatment of distal iliotibial band syndrome in a long distance runner with gait re-training emphasizing step rate manipulation. Int J Sports Phys Ther. 2014;9(2):222–31.
28. Kuster M, Wood GA, Sakurai S, Blatter G. Stress on the femoropatellar joint in downhill walking – a biomechanical study. Z Unfallchir Versicherungsmed. 1993;86(3):178–83.
29. Schwameder H, Roithner R, Müller E, Niessen W, Raschner C. Knee joint forces during downhill walking with hiking poles. J Sports Sci. 1999;17(12):969–78.
30. Peters P. Orthopedic problems in sport climbing. Wilderness Environ Med. 2001;12:100–10.
31. Paige TE, Fiore DC, Houston JD. Injury in traditional and sport rock climbing. Wilderness Environ Med. 1998;9:2–7.
32. Rooks MD. Rock climbing injuries. Sports Med. 1997;23:261–70.
33. Bhatt J, Glaser R, Chaves A, Yung E. Middle and lower trapezius strengthening for the management of lateral epicondylalgia: a case report. J Orthop Sports Phys Ther. 2013;43:11.
34. Lucado AM, Kolber MJ, Cheng MS, Echternach Sr JL. Upper extremity strength characteristics in female recreational tennis players with and without lateral epicondylalgia. J Orthop Sports Phys Ther. 2012;42(12):1025–31.

Windsurfing: The Physiology of Athletic Performance and Training

27

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27.1 Introduction

Windsurfing (also called boardsailing) is a surface water sport which combines components of surfing and sailing. The sport has full Olympic status and various international federations in promotion, while the IWA (the International Windsurfing Association) is the organization that unifies the sport. Sailboard characteristics vary with length ranging from 2.5 to 4 m (8–12.5 feet), width ranging from 46 to 93 cm (18–37 inches), and weight between 7 and 18 kg (15–40 pounds) (Fig. 27.1), while a sailboard can reach speeds of over 65 kph (40 mph) and ride waves [1].

The principle of windsurfing is simple; windsurfers stand on the board, with the feet roughly shoulder width apart and hold the rig with the hands for controlling the board. However, competitive windsurfing can be very demanding in physical condition as windsurfers have to execute several maneuvers with a variety of techniques which require a good physical condition.

Until the early 1990s, Olympic class windsurfing was considered as a sport with moderately intense physical activity [2]. Since November 1992, the technique of "sail pumping" maneuver was allowed in all Olympic windsurfing competitions and made the sport much more physically demanding [3–5]. Sail pumping is an action in which board sailors move the rig repeatedly in order to accelerate the board on the waves reaching higher speeds and thus being more competitive. During sail pumping, the peak muscular activity in the arm muscles has been found to be greatest while a considerable activation has been detected in shoulder muscles but much less activity has been recorded for the legs [6]. Particularly, sail pumping requires successive flexion-extension movement of the upper and lower limbs during the whole race, which usually lasts between 25 and 50 min depending on wind conditions [7]. Athletes' ability for repeatable sail pumping during the race is considered as crucial for the ranking points.

Sail pumping and boardsailing strategies in the race are influenced substantially by weather conditions during the whole duration of the race. Windsurfing in different wind force conditions (light, moderate, and strong) can demonstrate different physiological demands and determinants of performance. It becomes apparent that windsurfers have to follow tailored training programs to meet the physiological demands of races under every weather condition.

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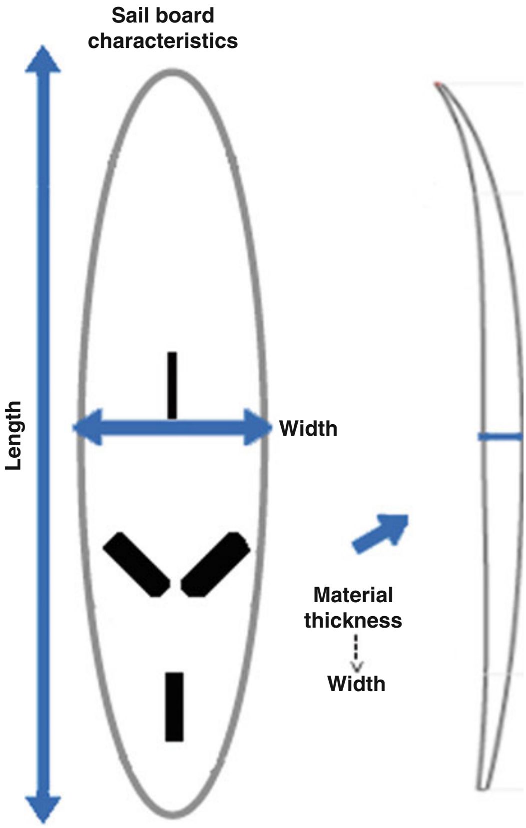

Fig. 27.1 The main technical characteristics of sailboard include length, width, and the material of board

27.2 Physiological Responses in Windsurfing

Windsurfing can be extremely demanding in terms of metabolic requirements as it combines surfing and sailing activity [8]. De Vito et al. were the first who demonstrated in actual sailing condition during Olympic boardsailing (Mistral board; sail surface 7.4 m^2, board length 3.70 m/width 63 cm) the profound metabolic demands entailing high energy and cardiorespiratory costs [3, 9]. Later, the energy demand of windsurfing was reassessed by Castagna et al. [10] who found that windsurfing with NeilPryde board (RS:X; sail surface 9.5 m^2; board length 2.86 m/width 93 cm), which substituted Mistral, has greater energy demands and requires high levels of aerobic and anaerobic capacity [10].

The metabolic profile of windsurfing can be described mainly as aerobic; however, the tactical and strategic decisions during a race require also a mixture of explosive-anaerobic force [11]. Specifically, aerobic capacity and fitness condition has been found to be directly related to sailors' reaction speed to wind shifts [12] particularly at the last stages of competition. The mean oxygen consumption can be higher than 80 % of VO_2max, the average HRmax can be over the 90 %, and the blood lactate concentration can correspond to the values recorded during a maximal treadmill test [3–10]. During the race, windsurfers often exceed their anaerobic thresholds at various intervals while the generated muscle forces can reach an average of 50 % of the maximum voluntary contraction (MVC) [5, 13, 14]. The intensity of the muscle contractions and number of simultaneously activated muscles [15] has been found much higher than in dingy sailing and during repeatedly tacks maximal activation of the arm muscles is attained [6].

In windsurfing, the physiological demands appear to be influenced by the strength of the winds. In light to moderate winds, sail pumping has been reported as the main reason for the demands of high levels of physical endurance [5, 16]. Indeed, the metabolic demands of windsurfing increase greatly (by threefold) when sail pumping is performed, as the oxygen consumption (VO_2max) can even reach 90 % of maximum oxygen uptake for prolonged periods of time [3, 5]. Furthermore, HR can be greatly increased with a mean HR ranging between 160 and 180 beats/min [5, 17, 18] depending on parameters such as the frequency of sail pumping based on wind force conditions and/or the types of muscle contractions during the windsurfing race [19]. There is a linear relationship between HR and exercise intensity [20]. Subsequent studies including HR measurements [4, 13] during actual windsurfing condition confirmed that sail pumping is a very demanding endurance activity which is closely depended to the heart's capacity to increase its output. Therefore, cardiac output – the product of heart rate and stroke volume (HR × SV) – has commonly been identified as one limiting factor of endurance performance [21].

Since the overall demands of aerobic capacity are high in windsurfing under light to moderate winds, lactate levels have been found also increased. Capillary blood lactic acid accumulation reaches an average of 8–9 mmol/l, which is much higher than the lactic acid concentration in dingy sailing [22]. High levels of blood lactate can be also one of the key reasons that limit the athletic effort [23] during sail pumping activity. In contrast, windsurfing under strong winds, which requires isometric contraction of the upper limb body muscles, is characterized by lower lactic acid accumulation which reaches on average the 3.0–5.0 mmol/l [24]. Even the relative low lactate levels (i.e., 3.0–5.0 mmol/l) sustained in isometric contraction of the upper limb muscles can be considered of sufficient intensity to induce muscle fatigue during contractions above 20–30 % of maximum voluntary contraction (MVC) due to ischemia [25]. Therefore, ischemia can be considered as an additional limiting factor of performance in windsurfing under strong wind conditions.

27.2.1 The Determinants of Windsurfing Performance

A good physical condition and muscular strength are generally considered as important characteristics for increased performance in Olympic boardsailing. The lower back, shoulder, and arm muscles have been identified for their high activation in windsurfing [14]. Upper body strength and endurance are critical for windsurfers to maintain control of board and achieve a good performance in regattas. However, in contrast to most other sports, wind force conditions have a crucial role in boardsailing performance as the wind velocity determines the frequency of sail pumping during boardsailing and provide a different pattern of physical effort based on the wind force conditions.

Sail pumping maneuver is considered substantially effective when the wind velocity is up to 15 knots (7 m/s) and requires a good aerobic capacity. In stronger winds, however, sail pumping loses its efficacy or it becomes so physically demanding [5]. This is due to the fact that pumping action is needed to increase the speed of the surfboard when the wind is not strong enough, but in high velocity winds, the technique is not effective. In strong winds, the nature of boardsailing physical effort is mostly isometric as the pumping technique is being replaced by a constant near isometric pulling power that is needed to control the board against the strong winds. Therefore, it is reasonable that the determinants of the performance in windsurfing are highly influenced by the wind velocity and the strategy followed during the race in which the frequency of sail pumping and the nature of physical effort (aerobic or isometric) differ.

27.2.2 Studies for the Effect of Light and Moderate Wind Force Conditions

In light to moderate winds, board sailors need to pump the sail repeatedly providing the board with additional speed. The first study that investigated the energy demands of sail pumping compared to non-pumping conditions was published in 2002 by the group of Vogiatzis et al. [5]. Physiological responses such as oxygen consumption (VO_2), minute ventilation (VE), and heart rate (HR) during the sail pumping were significantly increased compared to sailing without pumping in both men and women (Fig. 27.2) [5]. Moreover, all these parameters with an exemption of HR were significantly higher in men compared to women; however, these differences did not remain in non-pumping conditions between the sexes (Fig. 27.2) [5]. These observations have not substantially changed since 2006 when a new board (NeilPryde RS:X; 9.5 m^2men and 8.5 m^2 women) equipped with a larger sail was established for Olympic events.

Boardsailing in light to moderate wind conditions can be considered as a high-level aerobic activity when sail pumping maneuvers are frequently performed. The level of aerobic

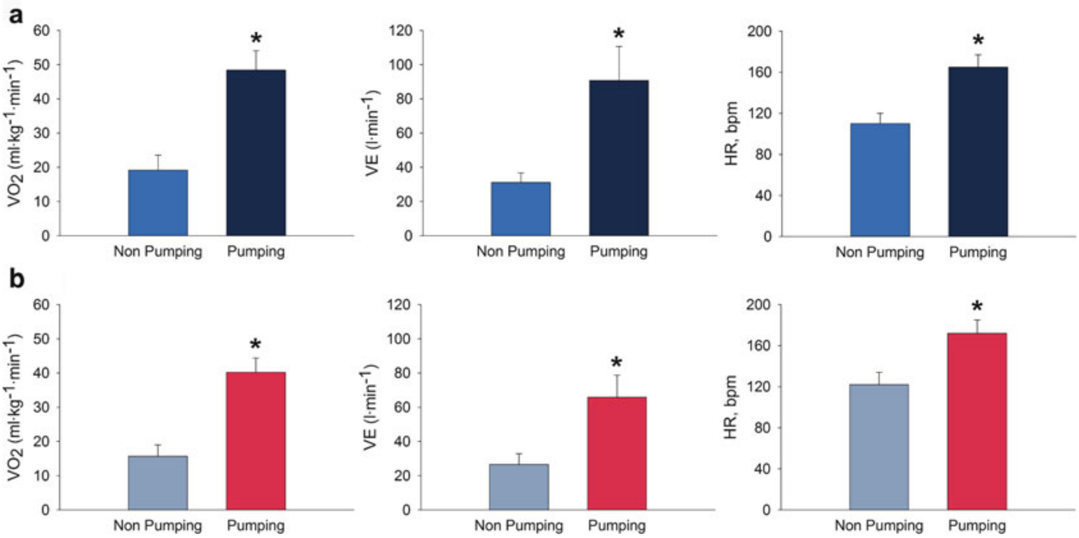

Fig. 27.2 Data of Vogiatzis et al. [5] demonstrated different physiological responses in oxygen uptake (*VO2*), ventilation (*VE*), and heart rate (*HR*) during boardsailing with sail pumping or without sail pumping in men and women. Data are means ±SD. *Asterisks* denote significant differences between with and without sail pumping condition. (**a**) Men, (**b**) women

capacity has been measured to range between 70 and 92 % of VO_2max similar to most of aerobic sports such as cycling, running, swimming, etc. [5, 16]. Moreover, the average HR during race in light wind conditions has been found to reach 170 beats/min, while average lactate concentration is approximately 8.5 mmol/l [19, 26]. Previously, differences in the HR increase during competitive boardsailing in two wind force conditions (light vs. moderate) have been reported regarding to sail pumping [4]. Guevel et al. [4] demonstrated that HR was higher in light compared to moderate wind force conditions (87 ± 4 % vs. 83 ± 5 % HRmax) while blood lactate concentration did not differ between wind conditions [4]. In general, light and medium wind Olympic windsurfing performance is highly dependent on the capacity of the athlete to maintain a high cardiac output for long periods of time with a maximal oxygen uptake of over 75 % [7, 19]. Moreover, high blood lactate accumulation can also impact negatively the performance of windsurfers in races with light to moderate wind force conditions as large amounts of lactic acid in the muscles can accelerate fatigue. It is reasonable that cardiac output can be identified as a key factor for the performance of windsurfers under light and medium wind force conditions. Cardiac output can become the main limiting factor in windsurfing under light to moderate wind conditions, as it can explains 70–85 % of the variance in VO_2max [21, 27].

27.2.3 Studies for the Effect of Strong Wind Force Conditions

In boardsailing races with moderate to strong winds (12–15 m/s), the demanding muscular effort is mainly isometric against the strong wind conditions, while the applied forces can reach almost the 500–800 N. A sustained isometric contraction of the upper limb body muscles is performed by athletes in an attempt to control the board under strong winds. Similarly to the hiking maneuver of sailors, the isometric contraction of the upper limb body of windsurfers can be considered of equivalent physiological characteristics. Previously, Vogiatzis et al. [28] observed low lactate concentration during prolonged hiking maneuver in sailing which could be attributed to the small oxygen and energy deficits as the muscles' oxygen accessibility is presumably partially restored during the brief rest intervals [28]. Equivalent results were found for competitive formula windsurfers as lactate concentration was significantly lower in strong compared to light winds conditions (2.9 vs. 8.5 mmol/l) [24]. The oxygen accessibility of muscles which are isometrically contracted can be sufficiently preserved during contraction and thus limiting the accumulated oxygen deficit and the significant rise of blood lactic levels [28].

A recent study which investigated the physiological characteristics of highly ranked and club sailors during successive hiking bouts demonstrated the superior central and peripheral muscle capacities for oxygen transport and utilization of high-ranked sailors [29]. These improved physiological characteristics compared to club sailors may explain the ability of top sailors for developing greater hiking moments [29]. According to the isometric nature of windsurfing under strong winds, windsurfers' performance in strong weather conditions may also depend on their ability to transport and utilize the oxygen in the isometrically contracting upper limb body muscles. Indeed, this ability may counterbalance the onset of muscle fatigue which can be mainly triggered by ischemia due to prolonged isometric contraction in windsurfing in strong wind force conditions. Therefore, central cardiovascular and local muscle metabolic adaptations that facilitate the oxygen transport and utilization of the windsurfers' upper limb body muscles may suggest the greater oxidative capacity (capillary network, mitochondrial volume, enzyme activity) on the part of high-ranked windsurfers.

27.3 Windsurfing Training

Windsurfer recommendations are often made on how best to physically and dietary prepare for the race. The use of periodization in training has been recommended [30]. Training should involve the shoulder girdle, as boardsailing requires sustained isometric action of the pectoralis major, deltoid, and scapular stabilizers [31]. Specifically, a completed training program for windsurfers should include the following three different types of physical training: (a) highly intense interval training with work and rest periods that closely resemble the pumping and relaxation periods, (b) moderately intense continuous training aimed at improving cardiovascular fitness and local muscle oxidative capacity, and (c) strength training to improve anaerobic power and capacity and to prepare the muscles for the explosive movements at the start and finish of a race and for getting around the marks [5, 32, 33].

In the first type of physical training, the training stimulus should range from 75 to 85 % of HRmax followed by short recovery periods between bouts of exercise. Training intensity for improving physical performance capacity should be around 75–85 % of HRmax corresponding to 160–170 beats/min with an active recovery ranged from 150 to 160 beats/min before the beginning of the next pumping or rowing bout. Pumping frequency should be set slightly higher from the exercise intensity which reaches the lactate threshold in order to minimize muscle lactate production [23]. Following the progression principle of training, the number and length of exercise periods should be increased while the training intervals for recovery should be shortened. The beneficial effects from this kind of interval training program will provide aerobic and anaerobic improvements and also will increase the athletes' tolerance to lactic acid accumulation and the lactic acid removal process [33].

The objective of the second type of training is the cardiovascular improvement. Cardiac output, the ability of the heart to transport large amounts of oxygenated blood to the muscles and the ability of the muscles to generate large amounts of energy in the presence of oxygen, can be improved by the implementation of a training program minimizing the production of lactic acid which induces muscle fatigue. Cardiac output is enhanced by (1) greater preload, (2) increased heart rate, (3) increased myocardial contractility, and (4) reduced afterload during exercise [27]. Training sessions have a usual duration of 60–90 min with warm-up/recovery and exercises intensity is on 60–75 % of HRmax corresponding to 140–150 beats/min. The form of exercise can include running, cycling, and simulated rowing (if it is applicable) [33].

The aims of the third type of training focus on the improvement of anaerobic power and capacity using training intensities over the 90 % of HRmax [33]. Improvements on maximal pull velocity are recommended [34]. Training at high intensity until exhaustion or training at a relatively constant effort but highly increasing the intensity at various intervals can improve the anaerobic profile of windsurfers. Recently, the maximal voluntary co-contraction have been suggested as an efficient training method for increasing the size and strength of antagonistic muscle pairs [35], and it could be incorporated in the training modalities of windsurfers. Due to very high intensity of anaerobic training, intervals are suggested with high intensity pumping periods of 10–40 s followed by 30–60 s of active recovery. Training bouts of six to ten repetitions with active recovery intervals twice the duration of work are recommended. The training frequency should be limited to two or three training sessions per week of this type of training [33].

27.4 Windsurfing Nutrition and Hydration

A diet rich in carbohydrates should be followed before and during training and racing days to maintain optimum glycogen level. Moreover, evidence has revealed that the predominant energy fuel during sail pumping is glycogen [5]. Overall findings suggest the need for dietary counseling in windsurfers, as glycogen depletion is crucial in windsurfing due to the fact that it can lead to insufficient energy for technical movements during sailing and thus direct affect negatively the outcome of the race [36]. A dietary program for increasing muscle glycogen content by diet rich in carbohydrates a few days prior to the competition has been highly recommended for endurance athletes [37, 38], but it can also be applied to windsurfers. During a race athletes need to ingest fluids (isotonic solutions) in order to replenish fluid, glucose, and minerals at the appropriate amount and rate. It is generally recommended that the pre-race meal should be low in fat and contain high amount of carbohydrates while it should be consumed at least 3 h before the start of the race. Moreover, especially in increased ambient temperatures, fluid replenishment should be taken every 15 min and should correspond to 1/4 of a liter. The alter races meal should be received within 1 h after the end of the competition. Due to the fact that glycogen resynthesis is related to carbohydrate intake, it is recommended the increase of daily carbohydrate intake to 70 % of total calories (approximately 8–10 g/kg for 3500 cal) or even higher in order to prevent the depletion of glycogen stores during successive days of competition [33].

References

1. Bornhoft S. Essential guide: windsurfing (essential guides). New Holland Publishers Ltd; UK, London, 2001. p. 810.
2. McLean B, Chad KE. Fitness characteristics of competitors in a six day sailboard marathon. J Sports Med Phys Fitness. 1992;32:250–4.
3. De Vito G, Di Filippo L, Rodio A, et al. Is the Olympic boardsailor an endurance athlete? Int J Sports Med. 1997;18(4):281–4.
4. Guevel A, Maisetti O, Prou E, et al. Heart rate and blood lactate responses during competitive Olympic boardsailing. J Sports Sci. 1999;17:135–41.
5. Vogiatzis I, De Vito G, Rodio A, et al. The physiological demands of sail pumping in Olympic level windsurfers. Eur J Appl Physiol. 2002;86:450–4.
6. Buchanan M, Cunningham P, Dyson RJ, et al. Electromyographic activity of beating and reaching during simulated boardsailing. J Sports Sci. 1996;14:131–7.
7. Guevel A, Hogrel JY, Marini JF. Fatigue of elbow flexors during repeated flexion-extension cycles: effect of movement strategy. Int J Sports Med. 2000;21:492–8.
8. Sedlaczek P. History, cultural context and terminology of Windsurfing. Stud Phyd Cult Tour. 2009;1(16): 115–23.
9. De Vito G, Di Filippo L, Felici F, et al. Assessment of energetic cost in laser and mistral sailors. Int J Sport Cardiol. 1996;5:55–9.
10. Castagna O, Vaz Pardal C, Brisswalter J. The assessment of energy demand in the new Olympic windsurf board: Neilpryde RS:X. Eur J Appl Physiol. 2007;100:247–52.

11. Resende NM, de Magalhaes Neto AM, Bachini F, et al. Metabolic changes during a field experiment in a world-class windsurfing athlete: a trial with multivariate analyses. OMICS. 2011;15:695–704.
12. Shephard RJ. Biology and medicine of sailing. An update. Sports Med. 1997;23:350–6.
13. Dyson RJ, Buchanan M, Farrington TA, et al. Electromyographic activity during windsurfing on water. J Sports Sci. 1996;14:125–30.
14. Loquet H, Guilbert J, Jacquesson JM, et al. Electromyographic study on a simulator of the practice of windsurfing. LARC Med. 1984;4:306–12.
15. Dyson R, Buchanan M, Hale T. Incidence of sports injuries in elite competitive and recreational windsurfers. Br J Sports Med. 2006;40:346–50.
16. Vogiatzis I, De Vito G. Physiological assessment of Olympic windsurfers. Eur J Sport Sci. 2014;15(3):1–7.
17. Schonle C, Rieckert H. Cardiovascular reactions during exhausting isometric exercise while windsurfing on a simulator or at sea. Int J Sports Med. 1983;4:260–4.
18. Vercruyssen F, Blin N, L'Huillier D, et al. Assessment of physiological demand in kitesurfing. Eur J Appl Physiol. 2009;105:103–9.
19. Chamari K, Moussa-Chamari I, Galy O, et al. Correlation between heart rate and performance during Olympic windsurfing competition. Eur J Appl Physiol. 2003;89:387–92.
20. ACSM. American College of Sports Medicine Position stand. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. Med Sci Sports Exerc. 1998;30: 975–91.
21. Bassett Jr DR, Howley ET. Limiting factors for maximum oxygen uptake and determinants of endurance performance. Med Sci Sports Exerc. 2000;32:70–84.
22. Narici M. Neuromuscular performance in sailing. 18th Annual congress of European college of sport science. Barcelona: Sailing Symposium; 2013;3–4.
23. Castagna O, Brisswalter J, Lacour JR, et al. Physiological demands of different sailing techniques of the new Olympic windsurfing class. Eur J Appl Physiol. 2008;104:1061–7.
24. Perez-Turpin J, Cortell-Tormo J, Suarez-Liorca C, et al. Relationship between anthropometric parameters, physiological responses, routes and competition results in formula windsurfing. Acta Kinesiol Univ Tartuensis. 2009;14:95–110.
25. Sjogaard G. Exercise-induced muscle fatigue: the significance of potassium. Acta Physiol Scand Suppl. 1990;593(140):1–63.
26. Allen G, Loke S. Physiologic responses of elite board sailing athletes during competition. 27th National scientific conference of the Australian sport medicine federation. Camberra; 1990.
27. La Gerche A, Gewillig M. What limits cardiac performance during exercise in normal subjects and in healthy fontan patients? Int J Pediatr. 2010;1(2010):1–8.
28. Vogiatzis I, Tzineris D, Athanasopoulos D, et al. Quadriceps oxygenation during isometric exercise in sailing. Int J Sports Med. 2008;29:11–5.
29. Andrianopoulos V, Louvaris Z, Orfanos I, et al. Quadriceps muscle oxygen availability between highly-ranked and club sailors during successive simulated hiking bouts. J Athl Enchancement. 2014;3:2.
30. Chamera T. The structure of the final preparation period and its effects on sport results of sailors taking part in the 2004 Olympic games. Stud Phys Cult Tour. 2007;Suppl.14:241–7.
31. Allen JB, De Jong MR. Sailing and sports medicine: a literature review. Br J Sports Med. 2006;40:587–93.
32. Vogiatzis I, Spurway NC, Wilson J, et al. Assessment of aerobic and anaerobic demands of dinghy sailing at different wind velocities. J Sports Med Phys Fitness. 1995;35:103–7.
33. Vogiatzis I. The physiological demands of – pumping– in IMCO windsurfing. 1999. http://formulawindsurfing-association.gr/forum/attachment.php?aid=316.
34. Lai H, Zheng W, Ge X, et al. Testing and evaluation of bench pull training of Chinese man elite board sailors. J Shandong Inst Phys Med Sports. 2008;1(2008):017.
35. Maeo S, Yoshitake Y, Takai Y, et al. Neuromuscular adaptations following 12-week maximal voluntary co-contraction training. Eur J Appl Physiol. 2014;114:663–73.
36. Doumtsios I, Grammatikopoulou M, Tsigga M. Diet quality and anthropometry between different sailboarding styles. Nutr Diet. 2010;67:31–6.
37. Cheuvront S. The zone diet and athletic performance. Sports Med. 1999;27:213–28.
38. Evans WJ, Hughes VA. Dietary carbohydrates and endurance exercise. Am J Clin Nutr. 1985;41: 1146–54.

28

An Ecological Dynamics Framework for the Acquisition of Perceptual–Motor Skills in Climbing

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28.1 Introduction

Climbing can be practised in many different environments, including indoors and outdoors; for differing heights, short (e.g. up to a maximum of 7–8 m in height called ‘bouldering’) or long ascents (e.g. from one pitch to multi-pitches of on average 20–30 m each); at low or high altitudes; on rocky, snowy, icy or mixed surfaces, with or without tools as support (e.g. ice axes, crampons or even ropes); in sport format (with bolts) or traditional (without bolts); or with more or less engagement with other climbers (e.g. solo, top rope or on-sight) [1]. These various climbing performance environments are often deliberately chosen by climbers and embody different degrees of ‘extreme sport’ characteristics. For instance, ‘free solo’ climbing represents the most engaged form of practice because the climber climbs at high levels without ropes where one mistake could result in a fall and death. As a consequence, the climber has to anticipate a range of issues, such as fatigue and weather conditions, in order to minimise additional risks. While the climbing moves and the physical exertion experienced by a ‘free solo’ climber 2000 m up a sheer cliff may be the same as when bouldering for hours at just a few metres off the ground, there are vast differences in psychological and emotional constraints between the two contexts. The consequence of a mismanaged mistake or accident while climbing at 2000 m without a rope is most likely death compared to mere irritation at a few metres height (for some relevant stories of solo mountaineering ascents, see, e.g. the book entitled ‘*Solos*’ written by the head coach of the national team of the French federation of mountain Alpine club [2]). The most challenging feature in this type of activity is that many environmental constraints are not under a

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climber's control. As such, a climber needs to rely on effective personal judgments, such as assessing the quality of ice or rock properties, risks of avalanches, weather forecasts, possibility of a fall back option or an escape route. The degree of environmental uncertainty in climbing, coupled with the ensuing psycho-emotional and physiological demands, categorises it amongst the most extreme of extreme sports. An interesting issue that we address in this chapter concerns the challenges for the acquisition of functional perceptual–motor skills in climbing. In his book entitled '*Mixed emotions*' [3], the American climber and writer Greg Child provided some relevant examples of 'extreme' conditions that could be encountered when climbing or mountaineering. This high level of uncertainty is further complicated by continuous changes in the environment and the lack of predictability when climbing surfaces are viewed from the ground. Our research on ecological dynamics discusses how performance may be considered as an ongoing coadaptation of each climber's thoughts and behaviours to a set of dynamically changing, interacting constraints which are individually perceived and acted upon. Here we elucidate key concepts from this theoretical framework and discuss how they may underpin skill acquisition and the enhancement of expertise in an extreme sport like climbing.

28.1.1 The Theory of Ecological Dynamics

In extreme sport performance environments, an 'ecological dynamics' framework yields valuable insights regarding the intertwined relations between cognitions, perception and action when individuals interact with environmental properties. This framework adopts a systems perspective to analyse the acquisition of skill and expertise in sport [4–7]. Ecological dynamics combines concepts from ecological psychology and nonlinear dynamics and applies them to representative performance and learning contexts for understanding the acquisition and transfer of adaptive human behaviours [8].

In ecological psychology, the organisation of human behaviour is predicated on the role of information that emerges from the performer–environment system to regulate action directly [9]. The most significant information sources that constrain performance behaviours are *affordances*, which provide *invitations for action* offered by each individual's perception of key properties of a performance environment [9]. This information-based approach has been enhanced with the addition of tools and concepts from nonlinear dynamics to explain how information is cyclically related to the dynamics of the performance environment [10]. Ecological dynamics highlights the coordination tendencies that exist between, and within, components and levels of complex neurobiological systems (e.g. human beings). System organisation is both facilitated and bounded by *constraints* which shape the dynamics of emergent behaviours [11]. Constraints on behaviours include task, performer and environmental factors. In this chapter, we discuss how an ecological dynamics framework is useful for identifying the key constraints that could define the 'extreme' characteristics of a sport like climbing. In particular, we discuss how the degree of performance 'extremity' could vary when climbing. For instance, is it more extreme to practice climbing a mountain route for 1000 m, when roped at 4000 m altitude or when soloing on a climbing wall as done by Alain Robert (the *French Spiderman*) when he climbs a high building. In these different cases, the constraints that define 'extreme' conditions are different: in one case, altitude, weather conditions and length of the ascent enhance the risks, while in the second case, soloing leads to a high level of engagement.

Additionally, in an ecological dynamics framework, the concept of 'representative design' underpins the design of experimental and learning environments so that observations and acquired skills can be linked to a specific performance context [12, 13]. The representative design framework provides guidance for the development of ecological constraints that best reflect performance interactions and their level of variability. This is an important feature of skill transfer as it ensures that cognitions, perceptions and actions used to regulate behaviour in one performance context (e.g. indoor climbing environments) can be expected to generalise to another context (e.g. outdoor climbing environments) [14, 15].

In summary, an ecological dynamics framework is a systems perspective that proposes that performer interactions with key objects (e.g. crampons and ice axes), surfaces (rock, ice and snow), events (sudden change in weather conditions) and significant others (belayer, other team members) during climbing occur through an active, emergent exploration of environmental properties that contribute to determine the degree of 'extremeness' in climbing. Next, we analyse the interactions between climbers and their performance environments and discuss empirical research that can help us understand how to guide climbers' perception of key functional properties in a performance environment and adapt their behaviours to achieve performance goals. The remainder of this chapter is split into three parts: we first unpack the main theoretical assumptions of the ecological dynamics framework and we discuss how it offers valuable insights to understand perceptual–motor behaviours and their acquisition in extreme sports such as ice and rock climbing. The second section highlights the key properties of expertise in climbing. As many inexperienced climbers mostly climb on indoor climbing walls without reinvesting their learning in outdoor and extreme conditions, we explain why behavioural 'adaptability' and skill transfer could be considered as the most important feature of expertise in extreme sports. Last, we provide practical applications for training climbing skills, in particular by investigating how representative learning designs can be achieved. As experienced climbers often train on indoor climbing walls for fitness, the final section highlights how to design a representative training task on an indoor climbing wall to maintain a degree of uncertainty in perceptual–motor constraints, to encourage behavioural 'adaptability'. As most published research in skill acquisition and climbing is based on observations of performance on indoor climbing walls, we seek to emphasise how the main findings of these studies could relate or be extended to more 'extreme' performance conditions.

28.2 Perceptual–Motor Skill Acquisition and Transfer in Ecological Dynamics

Skill acquisition refers to the acquisition of an adaptive relationship between each individual and a performance environment [16]. Changes can occur in structural features of each individual's biological tissues (such as when strength training stabilises specific movement patterns constraining how each individual functionally responds to different performance demands [17]). Changes also occur at a psychological level. For example, training indoors for solo multi-pitch climbing would work well for developing physical strength or movement capabilities. But it might not prepare a climber for the self-awareness or planning required for successfully undertaking extended expeditions, enhancing capabilities around mental focus for extended periods or managing fear where a small mistake could end in death [18]. Functional behavioural adaptations during learning lead to persistent changes in how information is related to action [19]. Skill transfer emerges from the influence of prior experiences under a particular set of interacting constraints on performance under a different set of constraints compared to those where the skills were acquired [20]. Skill transfer can be characterised as positive (performance is improved under different constraints than would otherwise be the case without learning), neutral or negative (performance is worse under different constraints as would otherwise have been the case without learning) [21, 22]. Positive transfer can occur when the existing intrinsic dynamics (i.e. performance disposition or tendencies) of an individual cooperate with the dynamics of a new task to be learned. Negative transfer occurs when intrinsic and task dynamics compete [10]. An interesting issue to be considered concerns whether the intrinsic dynamics (performance tendencies) of an individual climber who practises regularly on an indoor climbing wall might cooperate or compete with the task dynamics of rock or ice climbing.

Furthermore, transfer can occur along different domains of performance, including near (or vertical transfer) and far domains (horizontal transfer) [23]. Near domain transfer refers to when skills are generalised to a new set of constraints that although different maintain interactions amongst key constraints (such as similar limb coordination patterns but different types of hold grasping patterns) [24]. Far transfer refers to an 'across-domain' transfer where separate subsystems become important (such as different decision-making process, physiological or psychological aspects). For example, additional psychological requirements will be required when undertaking a solo traverse at 2000 m compared to an indoor training environment. In this instance, decision making will involve the physical capacity required not just to undertake the traverse but also to perform while understanding the consequences of a mistake. A fifty percent chance of success one metre from the ground when training may be workable, but at 2000 m, these odds would be untenable. How structural and functional adaptations contribute to transfer is poorly understood, although it is becoming clear that expertise can have a strong influence over the degree of transfer of performance [23, 24].

28.3 Skill as an Emergent Property to Constraints

In ecological dynamics, skill is considered to emerge from the continuous informational exchanges between an individual and a performance environment under interacting constraints [5, 16]. Constraints place boundaries on informational exchange and do not predetermine how behaviours will be organised – rather skilled performance is an emergent, self-organising process [5]. Patterns of movement coordination between limbs, relative to key surfaces, objects, events and significant others, are functionally organised to satisfy interacting constraints on performance. Therefore, from this viewpoint, there is no one ideal motor coordination solution towards which all climbers should aspire [7]. In the same vein, there is no ideal psychological state that a performer should aspire to replicate during performance. Rather functional patterns of behaviour emerge from the interaction of constraints [11]. Newell [11] defined three types of constraints: environmental, task and organismic (personal). Personal constraints are structural or functional and refer to characteristics of an individual such as genes, anthropometric properties, cognition, motivation and emotions, for example, climbing, especially in severe weather conditions, or when soloing, which is very psychologically demanding. Alain Robert, called the *French Spiderman*, used to vigorously practise solo climbing often resulting in dramatic falls. However, Alain Robert says: '*Climbing is my passion, my philosophy of life. Although I suffer from vertigo, although my accidents left me disabled up to 66 %, I have become the best solo climber*' [25]. As a result of these accidents, he is no longer able to perform some grasping and body movements essential for rock climbing and adapted his activity to solo climbing the highest buildings in the world [26]. This example shows that even with additional personal (physical) constraints, climbers can continue practising solo climbing at the highest level. In effect, psychological capabilities seem to outweigh physical capabilities in regulating solo climbing performance.

Environmental constraints are external to an individual and can be physical, reflecting the environmental conditions of the task. In climbing, temperature and altitude can make the ascent harder. For instance, it is well known that a high ambient temperature can cause swelling in the feet, which means that climbing becomes uncomfortable. Humidity can cause a climber's hands to become sweaty, which challenges the graspability of holds. Steepness of a rock cliff can change from a positive inclination (i.e. ramp) to a negative inclination (i.e. overhang), which obviously challenges climbing techniques. Specifically, a particular ramp might favour smearing (i.e. using climbing shoe friction), whereas an overhang often involves actions like arm pumping and feet hooking for improving one's position on the surface. In ice climbing, the thickness of the ice may influence how deep a blade might anchor in an icefall. Moreover, some icefall properties tend to be stochastically distributed throughout its surface, requiring ongoing regulation of behaviours (e.g. movement exploration, perceptual prospection), rather than relying on advanced planning. Icefall properties interact with ambient temperatures to modify ice density in certain regions of the icefall, sometimes during a climb. The quality and type of rock surface often afford specific climbing actions. For instance, in rock climbing, limestone often affords interacting with crimp, pinch and pocket, while granite mostly affords actions to negotiate surface cracks. Gravity is a most significant physical environmental constraint because quadruped vertical locomotion involving the minimal support of at least one limb is required to prevent falling under gravitational forces.

Task constraints include the goal of the task, the rules, boundary locations, instructions or equipment specifying a response. In climbing, performance typically involves quadruped body displacement using extremities of fingers and feet or tools (such as ice tools and crampons in ice climbing). Because of these specific task constraints, the control of actions with respect to gravitational forces is much more challenging than during human pedestrian locomotion in the horizontal plane. Climbing performance is characterised by individuals needing to maintain body equilibrium on a climbing surface [27] by integrating upper and lower limb movements to ascend a surface [28, 29]. Typical performance constraints demand the acquisition of specific perceptual–motor skills such as postural regulation [27, 30–32] and intra- and interlimb coordination [33, 34], route finding [35, 36] that could be optimised by visual previewing [37], movement variability to vary types of hold grasping methods [38] or ice tool usage [33] and affordance perception [39] (Table 28.1, Fig. 28.1).

In Europe, this set of constraints led to the development of a double grade scale in mountaineering, traditional rock climbing and ice climbing: difficulty of the route (with grade from E-easy to ABO-abominable) and engagement of the route (with grade from I to VII, depending on the rate of objective danger like possible fall of stone or ice, risk of avalanche, possibility of escape, fall back, rescue) [40, 41].

The constraint-led approach has some practical implications for learning and training in climbing. Facilitating learning involves manipulating constraints on the coupling of information and movement to guide an individual's exploration of their own functional properties during performance adaptations [42]. This exploratory activity is functional because it allows individuals to discover ways of picking up relevant information for action. Task exploration results in patterns of coordination that may be unique, or previously stable, which may result in the improved stability of these patterns both for their retention and for their transfer to modified constraints. Additionally, practice that induces exploration is also valuable because it helps individuals learn how to harness inherent self-organising tendencies. In extreme sport contexts, this is particularly important, in that performance needs to be emergent on the basis of the highly unpredictable nature of environmental constraints [14].

Ecological dynamics proposes that learning environments should induce emergent exploration. For example, a leader might lead learners on climbing routes that exhibit a degree of uncertainty that reflects the performance context. In fact, the uncertainty region of performance involves destabilising existing information–movement couplings to some extent so that different actions can emerge. According to Warren [43], this aim can be achieved by exploiting an affordance-based control approach. That is, under specific ecological constraints, boundaries invite multiple opportunities for action. These same boundaries provide opportunities to observe fluctuations in movement behaviours [44]. Certainty emanating from variability of available information and from the process of deciding what actions to use can be harnessed to support performance. Depending on climbing formats, learning contexts can be designed to determine which constraints can be manipulated.

Next, we explain how movement variability could be functional and adaptive, in order to induce exploration and discovery learning.

Table 28.1 Example of the main constraints acting in climbing

Category of constraint	Specific	Application (scaling)
Task	Instruction	Required climbing speed, technique/behaviour, attentional foci, feedback
	Safety demands	Lead climbing (securing ascent with existing/temporary bolts), top roping, seconding (removing bolts), multi-pitch, single pitch, solo, safety mats
	Practice	On-sight, red point
	Preview	With preview, without preview, flash
	Expectations	Knowledge of route characteristics (e.g. difficulty level, route history)
	Specialised equipment	Chalk, chalk bags, resins, helmets, ice tools, crampons, ropes, bolts
	Rules	Competition, point systems, for time
Environment	Route material properties	Artificial (dirty, clean), ice, rock (various types – chalk, granite, etc.)
	Weather	Protected (indoors), exposed, light, wind, rain, snow, moisture, humidity, heat
	Altitude	
	Significant others	Team climbing, belayer, climbing party, coach, audience
	Wall	Slope, texture, colour, height
	Holds	Texture, colour, edge(s), size, orientation, insets, smoothness
	Traversal characteristics	Horizontal and vertical inter-hold distances, crux, continuous difficulty, escalating difficulty
Individual	Psychological	Trait and state anxiety, risk-taking personality, sensation-seeking traits, psychological factors (e.g. fear, acceptance of the possibility of death, arousal control, self-awareness, resilience, focus, elation)
	Ability level	Complete beginner, lower grade intermediate, advanced, elite, higher elite
	Anthropometric, physiological, gender, strength-based factors, developmental factors	
	Developmental experiences	

28.4 Functional Movement Variability and Degeneracy

Research in ecological dynamics has shown that movement system variability is not necessarily noise that is detrimental to performance [45–47], or a deviation from a putative expert performance model, which should be corrected in beginners [7]. Instead, variability may be functional to support adaptive behaviours [4]. Consideration of the functional role of movement variability leads to an exploration of appropriate *adaptive* behaviour. Adaptability relates to an appropriate relationship between *stability* (i.e. persistent behaviours) and *flexibility* (i.e. variable behaviours) during performance [43, 48, 49]. Skilled climbers are able to exhibit stable patterns of behaviour when needed, but can vary actions depending on dynamic performance conditions [50]. Although human movement systems have a tendency to become stable and more economical with experience and practice [51], stability and flexibility are not opposing characteristics of performance. Notably, flexibility is not a loss of stability but conversely is a sign of adaptability [43, 49] and is essential for skilled performance in extreme sports such as climbing. Even if movement patterns showed regularities and similarities within their structural components, an individual is not fixed into performing a rigidly stable solution, but can adapt an emergent movement pattern in order to maintain

Fig. 28.1 Example of how constraints interact in climbing for which training can allow possible skills transfer: We illustrate the performer–task interaction where the use of safety equipment could relate to three types of psychological engagement such as 'free soloing', 'tope rope', 'on-sight' climbing. We illustrate task–environment interaction where three types of tool use such as ice tools and crampons in ice climbing, belay for abseiling, stopper and spring-loaded camming devices for traditional rock climbing allow climbers to explore various environments. We illustrate environmental–performer interaction where three types of climbing environments (e.g. surface and texture) such as mixed route (snow, ice and rock) in high-altitude mountain climbing, small but intense bouldering problems and limestone rock cliffs can lead to unique behavioural and physiological adaptations

behavioural functionality. When a gap existing between a stable movement pattern repertoire of an individual and the demands of a task is small, and/or when the tasks constraints are weak, movement variability will likely emerge. The capacity for an individual to adapt to environmental changes exploited through different coordination patterns reflects neurobiological system degeneracy. Edelman and Gally [52] originally defined degeneracy as 'the ability of elements that are structurally different to perform the same function or yield the same output'. Degeneracy allows an individual to vary motor behaviour (structurally) without compromising function, revealing the adaptive and functional role of coordination pattern variability at different levels of organisation (i.e. within and between individuals), in order to satisfy task, environmental and organism constraints. Mason [53] recently outlined important sources of degeneracy in movement systems, including (i) structural duplication (e.g. using either hand to perform different functions), (ii) structurally different parts of the movement performing the same function (e.g. using a hand or foot to make contact with a surface), (iii) the ability of different parts of the movement to come together in different ways to achieve the same function (e.g. components of a coordination pattern being more functional as environmental conditions change) and (iv) for the same part of a movement system to achieve the same function in different ways (e.g. a hand being used to grip a surface feature in different ways depending on its orientation). System degeneracy is a platform for complex systems to dissipate energy coming into the system that might otherwise perturb it and is hence intimately linked with explaining how neurobiological systems are able to self-organise into functional patterns [52]. Degeneracy is a central principle in an ecological dynamics framework for explaining the sources of within- and between-individual variability that arise during learning and performance.

A good example of degeneracy in rock climbing is the large range of hand grasping patterns and body positions regularly used to achieve a specific hold (e.g. crimp, gaston, jug, mono, pinch, pocket, sloper and undercling grasping patterns; bridge, campus, crossover, deadpoint, flag, heel hook, knee bar and mantle body positions; see also [1] exhibiting several individual climbing profiles). Similarly, in ice climbing, recent studies have revealed that climbers exhibit several stable patterns of motor coordination (e.g. horizontal, diagonal, vertical and crossed located angular positions of the ice tools and crampons) to achieve specific task goals [33, 34, 53]. These multistable patterns of coordination reflect a functional adaptation to dynamic environmental properties. In particular the location of the anchorage and the type of actions used to anchor the ice tools and crampons were selected to protect the icefall structure. Ice tools are usually separated from each other by 20 cm to protect icefall surface structure, which might be fragile in some parts. Similarly, different types of actions could be realised by individuals (i.e. swinging, kicking or hooking), depending on the icefall shape. When the ice is dense without any holes, climbers usually swing their ice tools and kick their crampons. Conversely, when the ice is hollow, climbers hook holes with their ice tools and crampons. Thus, the functional ability of each climber to vary the types of action used to engage with the dynamic properties of each specific icefall has been quite easy to assess by analysing the types of actions undertaken by the climber. Thus, the multistability of coordination patterns has been revealed by observing the efficient coupling of a skilled climber with properties of a performance environment, likely predicated on inherent neurobiological system degeneracy [52, 54]. From there, one key challenge is to effectively perceive information, which is meaningful in terms of action opportunities (affordances).

28.4.1 Perception of Affordances and Movement Coordination

Affordances are action opportunities invited from an individual, which are predicated on *knowledge of* a performance environment [9]. In measurable terms, the environment is composed of physical properties (such as light amplitudes or surface hardness), and the individual is made up of measurable action capabilities. The relationship between the physical properties of the environment and the individual's action capabilities constitutes an affordance [55, 56]. Affordances can be linked to movement coordination because they have qualitatively distinct characteristics, with regions of stability and transitions that self-organise based on the informational properties of the performer–environment relationship [43]. In climbing, affordances refer to 'climbing opportunities' [57], i.e. environmental properties that invite hold reach-ability, grasp-ability and climb-ability. Perceiving opportunities for specific actions when climbing requires perceptual attunement to and calibration of relevant informational variables, meaning that climbers need to pick up a range of perceptual variables from different system modalities (haptic, kinesthesis, auditory, visual) that specify a relevant property of a performance environment [58, 59]. The term 'relevant' signifies functionality, as this property enables an individual performer to achieve a specific task goal with efficacy. Efficacy in affordance perception during extreme sport performance, like climbing, can be empirically assessed by distinguishing *exploratory* and *performatory* movements of athletes, according to whether a potential hold on the rock surface was touched, with or without it being used as support [34]. The relation between exploratory and performatory movements has been analysed through recording the ratio of touched holds and grasped holds, for which climbing skills is usually defined by the 'three-holds-rule'. It has been reported that skilled climbers can move quickly by using fewer than three holds, signifying that they had touched fewer than three surface holds before grasping the functional one for successful performance [60]. Previous studies have already shown how *route or hold design* induces more or less exploratory behaviour. For instance, grasping of horizontal edge holds can lead to the adoption of a 'face-to-the-wall' body orientation, whereas vertical edge hold grasping can induce a 'side-to-the-wall' body orientation [61]. Therefore, designing complex climbing routes, with holds offering dual edge orientations, invites climbers to explore two types of grasping patterns and body orientations [61]. In fact, moving between a right-orientated vertical edge hold to a left-orientated vertical edge hold would lead the body to rotate as if on the hinges of a door. Hold design has been found to influence movement patterns of climbers, and especially movement time during hold grasping [38]. More precisely, complexity of manual grips (2 cm *vs*. 1 cm depth) and posture difficulty (low *vs*. high angle of inclination of foot holds) resulted in shorter movement times for grasping (notably, longer times to reach maximum acceleration and shorter times to reach the maximum deceleration) [38], with less time spent exploring.

In ice climbing, attempts to identify perception of affordances can be achieved by observing the actions of climbers to understand whether they swing their ice tools to create their own holes to support body weight or whether they perceive and hook existing holes (left by actions of previous climbers or by exploiting the presence of natural holes in the ice fall surface) [34]. Indeed, when the ice is soft or ventilated, climbers can anchor their ice tools and crampons in one shot, enhancing energy efficiency. Conversely, when the ice is dense and thick, climbers need to repeat numerous trials of ice tool swinging and crampon kicking to attain a safe anchorage. Usually skilled climbers can detect modifications to the thickness of the icefall in order to minimise the frequency of actions they need to complete before achieving a definitive anchorage [41]. Therefore, observing the frequency of actions to anchor ice tools can reveal the perceptual attunement of each climber to icefall properties to exploit during performance.

28.5 Key Properties of Expertise in Climbing

Johnson [62] defined expertise as the combination of speed, accuracy, form and adaptability. In fact, Johnson [62] documented an interesting fable that captures this characterisation of expertise by comparing Swedish and Finnish woodchoppers. In the fable called 'The Woodchoppers' Ball', both Swedish and Finnish lumberjacks were able to chop ten cords of wood at the same speed, with the same accuracy levels in splitting matches and straws, hitting pencil marks and bird shot. Since form was related to effort and economy (e.g. the minimal amount of energy expenditure was expected), both Swedes and Finns chopped the same amount of wood in 2 h. However, when a novel task was sought to compare the performance of the two sets of woodchoppers, the issue of movement adaptability was raised. Adaptive skill implied that performance remained proficient under varying and even unpredictable environmental constraints. The Swedish woodchopper was the only one to chop wood of various heights and to chop with various types of axes [62]. By highlighting the importance of adaptability in a comprehensive definition of expertise, Johnson [62] was implicitly raising questions on the role of movement variability. As suggested previously, an ecological dynamics model of expertise articulates the roles of stability and flexibility: experts and non-experts each have their stable states and sometimes share the same coordination patterns. However, a particularity of expert performance is the capacity for adaptability, i.e. to produce behaviour, which is stable when needed and variable when needed. Expert behaviour is characterised by stable and reproducible movement patterns, which are consistent over time, resistant to perturbations and reproducible in that a similar movement pattern may recur under different task and environmental constraints. However, it is not stereotyped and rigid but flexible and adaptive. As stated previously by Johnson [62], expertise is a function of the combination of different characteristics.

In rock, ice and mixed climbing, and particularly in extreme mountaineering, adaptability of perceptual–motor skills enables a rapid ascent up a vertical surface. *Speed* is a criterion of success and survival because the faster one climbs, the shorter the length of exposure to danger, especially in places like the high-altitude summits of the Himalayas where weather conditions can alter rapidly. The professional Swiss mountaineer, Ueli Steck, considered as the fastest climber in the world, exemplifies this rule. In his book, 'Speed', Ueli Steck [63] explains how he broke the speed record when he performed a soloing ascent of three famous North faces in the Alps: the Eiger (in 2 h 47′ by the Heckmair route in 2008), the Grandes Jorasses (in 2 h21 by the Colton-MacIntyre route in on-sight climbing in 2008) and the Cervin (in 1 h 56′ by the Schmid route in on-sight climbing in 2009). Ueli Steck has also applied speed climbing in the Himalayas on summits up to 8000 m, with the South face ascent of the Shishapangma (8013 m in 10 h 30′ in 2011) and the soloing ascent of the South face of the Annapurna (8091 m in 28 h in 2013). Notably, the first summiteers of these mountains took four days to climb the North face in 1938.

Therefore, speed in body displacement may reveal functional movement variability because less time is spent exploring the functionality of a movement pattern. However, more than speed (revealing the performance outcome), climbing 'fluency' could be a good indicator of efficiency and adaptability to constraints. Climbing fluency usually involves the spatial–temporal assessment of a climber's centre of gravity or hip motion. For instance, climbers can exhibit saccades (variations in speed) and/or different trajectories of hip displacement when they explore hold grasping [34, 60] as well as longer pauses dedicated to the tasks of active resting [64], route finding [35, 36] and postural regulation [27, 30].

In the following sections, we present the contributions of studies from the perspective of the ecological dynamics rational for understanding how expert climbers exhibit higher adaptability of their motor skills and better perception of affordances than novices and, how in return, these skills impact on climbing fluency.

28.6 Functional Movement and Coordination Patterns Variability: Adaptability

A prominent characteristic of the adaptability of experts relates to their capacity to demonstrate functional variability in coordination patterns. Indeed, due to their extensive experience in different performance contexts, experts exploit to the fullest their individual abilities to satisfy task and environmental constraints. Moreover, since environmental constraints are neither predictable nor controllable, climbing requires experts to use numerous types of actions and patterns of interlimb coordination during performance by exploiting system properties of degeneracy [7, 33]. In fact, our evidence revealed that, to interact as they did with key environmental information constraints, expert climbers tend to alternate their exploitation of horizontal, diagonal, vertical and crossed angular limb positions on an icefall surface, exploiting the functionality of intra-individual coordination pattern variability. Indeed, to achieve that level of performance, expert climbers sometimes moved their right and left limbs across the vertical midline of their bodies to exploit surface properties and hook existing holes in an icefall [33]. Indeed, ice climbers tended to either swing their ice tools to create their own holes or hook an existing hole when the icefall structure is soft or ventilated, supporting the functional role of intra-individual variability. Conversely, beginners showed a more constricted range of movement and coordination patterns as they tended to adopt a basic quadruped climbing pattern that resembles climbing a ladder. In particular, the limb anchorages employed by beginners remained the same with both arms (or legs) extended (or flexed), corresponding to simultaneous muscular activation of arms (or legs) [34]. This strategy involved freezing available motor system degrees of freedom which is quite understandable, given that beginners in ice climbing tended to prioritise stability and security of posture rather than taking risks to climb quickly, with insecurities about their support (anchorage of ice tools and crampons anchorage).

28.7 Perceptual Attunement and Calibration of Informational Variables and Affordance Perception

An important characteristic of expert climbers is their perceptual attunement to relevant informational variables, revealing that experts are better at perceiving climbing affordances than beginners. In ice climbing, [33] showed that beginners seemed mostly attuned to visual characteristics of the icefall, as they focused on the size and depth of holes and steps. Beginners exhibited a global perception of icefall shape for which big and deep holes in icefall were synonymous with deep and confident anchorages. This unique perceptual approach to perceiving functional icefall properties resulted in them not varying their limb coordination patterns enough. In particular they tended to display a static 'X' or spider-like body position that allowed them to maintain equilibrium, with respect to gravity. However, these positions do not provide them with sufficient mobility on the ice surface, because once one limb is moved from the ice fall, beginners quickly perceive a lack of stability. Therefore, they infrequently varied the types of actions they used, mostly corresponding to swinging their ice tools, an activity likened to 'hammering'. Moreover, they tended to over-repeat the same actions in order to create a deep hole anchorage, which is a mark of confidence. Conversely, expert ice climbers exhibited greater perceptual attunement to visual, acoustic and haptic sources of action specifying information, which allowed climbers to detect 'use-ability' of holes in an icefall. Attunement to icefall properties (e.g. thickness, density, shape and steepness) that a climber might come across during an ascent may specify hole properties revealing how a climber might interact with surface structure signified by various actions such as ice tool swinging and hooking [33]. Climbing skill level and past experiences seem to influence the nature of specific environment–performer couplings and the manner of perceiving affordances, since only experts could vary their motor behaviours to save energy, balance their body and maintain constant climbing fluency and speed of ascent. Indeed, experts exhibited functional multistability of their coordination patterns and types of action (e.g. ice tool and crampons swinging and hooking).

A similar capacity to perceive affordances has been observed in experts on indoor climbing walls. Boschkner et al. [57] showed that, unlike beginners, expert rock climbers did not tend to perceive the structural features of a climbing wall, but they recalled more information than novices and focused on its functional properties, displaying greater exploitation of climbing affordances. The implication is that affordances do not exist independently of an individual's perceptions but are linked to experience and skill level. In the context of rock climbing, affordances result in the coordination dynamics of action emerging from a mutual coupling of a climber's perceptions and intentions with the specific properties of a climbing surface, such as a rock cliff (i.e. shape, steepness, type of rock). As environmental properties of the rock cliff are mostly not predictable from the ground, it is important to examine whether and how expert climbers detect information during a pre-ascent climbing route visual inspection (i.e. route preview) [37] or when observing a model [28] and how they recall climbing surface properties once they are in the ascent. Pezzullo et al. [65] compared the capacity of expert and novice climbers to preview and recall sequences of holds composing easy, difficult and impossible routes. When the climbers were voluntary distracted between the route preview and the recall, they [65] reported that a greater level of movement expertise enabled a better recall of sequences of holds on difficult routes. They proposed that route previewing on a climbing wall activates an embodied simulation, which relied on the motor competence of the climbers. Sanchez et al. [37] highlighted that route previewing did not influence movement output performance, but influenced movement form. Notably climbing fluency was better after a preview of the route since climbers made fewer and shorter stops during their ascent. Moreover, climbing fluency was found to be higher when observing other climbers [28]. Boschker and Bakker [28] evaluated the behaviour and performance of three groups of participants who, prior to the experiment, had no experience with climbing. Each group climbed a wall five times and prior to each climb viewed footage of either (i) an expert (a professional route setter) climbing the wall and overcoming a crux point with a cross hand pattern (where the hands cross in grasping a hold allowing the centre of mass to swing, considered an expert pattern); (ii) the same expert climbing the wall and overcoming a crux point using a dual grasping pattern (where two hands are placed on the same hold side-by-side to generate force, considered an early learner pattern) and (iii) a control group that observed footage of the climbing wall only. The group that observed the arm crossing movements climbed the wall faster (by the second climb) and with greater fluency than the dual grasping and control groups.

Finally, these findings showed that, with increasing levels of expertise, climbers previewed and recalled perceptual variables that are more functional (i.e. those which can specify actions) under a variety of different performance circumstances compared to novices who tended to focus and recall structural properties of the climbing environment. The use of expert demonstration can reduce anxiety and enhance perception of affordances.

28.8 Practical Applications for Training Climbing Skills

Some climbers may choose not to train on cliffs or mountains, because of fear or a lack of confidence in their ability to correctly assess requirements for altitude, weather conditions and unmarked routes or they may simply live too far from the mountains. Moreover, some expert climbers deliberately use indoor climbing walls for fitness training because weather conditions and route conditions do not allow daily practice. As such, it is imperative that there are effective ways of designing representative learning and training sessions that represent uncertainty and the psychological requirements of extreme climbing in indoor climbing wall contexts. In this way, we are better able to prepare climbers to overcome extreme conditions during outdoor climbing or mountaineering. In other words, performers and practitioners aim to train transferrable (or generalisable) skills [66]. A variety of reasons might underpin this approach, such as seasonal weather, safety concerns, increasing training volume or a belief that practice in one setting can improve performance in another. Indeed, such beliefs may have been shaping how people practice since climbing first emerged; in a nice historical review, Fryer [67] recounted how pioneering British mountaineers, who would undertake seasonal expeditions to the Alps, reportedly began to practise various skills on local crags for improving their mountaineering ability [67].

As found in much of the literature discussed thus far, most research in climbing has been undertaken in indoor top-roped and bouldering conditions, which might not reflect constraints in extreme environments. Notably a number of more recent studies have been performed during competitions [68, 69], under lead-rope conditions [70] and on icefalls [33, 34, 71]. Much more work can be done especially as only one study could be found to have addressed transfer-related questions. Seifert et al. [61] evaluated the role of experience in skill transfer from a known climbing genre (indoor climbing) to a climbing genre that was novel for participants (ice climbing outdoors). In their study, data showed that experienced climbers, who had previously acquired multiple movement patterns, were able to transfer climbing fluency to the novel task constraints of ice climbing – supporting in principle the notion that constraints can be represented to support the generalisability of skill across different climbing genres.

In the next section, we consider how constraints can be designed to support the generalisability of skill. We first discuss the representative design framework and how it may be integrated for designing training contexts for observing climbing-specific performance and learning behaviour. We then summarise climbing-specific constraints and how they might be represented for the purpose of inducing learning. We then focus on specific examples where climbing constraints can be manipulated to position learners in the exploratory regime of performance for the purpose of supporting transferrable skill acquisition.

28.9 Issues Surrounding Representative Experimental and Learning Design in Climbing

The climbing skills of expert climbers that satisfy the challenging constraints of this extreme sport activity can be summarised as efficient exploration, perception and use of climbing affordance, knowledge of a richer variety of climbing affordances during route traversal and finally, the ability to adapt skills to the dynamic qualities of constraints [33].

From a psychological perspective, extreme climbers require a variety of capabilities including (but not limited to) the capacity to psychologically prepare for the potential of risk, resilience especially when times get tough, considerable self-awareness and self-trust, psychological flexibility, the ability to cope with danger and manage fear so that it does not interfere with movement capacities, the capacity to visualise routes and remember them when in motion and the capacity to initiate and maintain focus for extended periods of time [72–76]. For example, the free solo ascent of the half done by Alex Honnold in 2008 was punctuated by a period of self-doubt and existential self-reflection. However, Alex Honnold managed to refocus and continue to the top without incident. Normally this trip takes a few days; in Alex Honnold's case, the ascent took just a few hours [77].

Across the climbing genres, core constraints can be identified that can serve as starting point for learning design. Fundamental task constraints include a target location to climb to (such as final hold or a summit); environmental constraints include surfaces that afford traversal with four points of support, and the individual needs the intention for traversal. A final constraint might also be the ability to grade the difficulty of the route according to some agreed-upon standard (and can include the difficulty of the entire route, the hardest part of the route known as the crux region, etc.). This may help the learners to have a clearer idea about their achievement and allow them to relate their achievements to previous levels of success and to other climbers (acting somewhat as a social constraint).

In manipulating constraints, the information–movement couplings used during climbing can be influenced towards more or less stability and can promote the exploration of different and possibly new patterns of coordination [4]. With practice, it can be expected that individuals adapt towards consistent methods of traversal [36] allowing them to learn on how to stabilise and refine their movement coordination. In order to continue challenging the individual to explore available degeneracy, such as different climbing affordances for traversal, constraints need to be further manipulated [42]. In the following section, we complete this chapter with two applied examples of how exploration can be induced through constraint manipulation to position individuals in the metastable performance region, for both low- and high-experienced climbers.

28.10 Representing Constraints for Training Transferable Climbing Skills

In inexperienced climbers, one of the limitations faced is an inability to use a variety of functional coordination patterns for traversal. From a psychological perspective, the ability to effectively manage arousal and remain relaxed enables physical range of motion [34]. For many beginners, the idea of climbing creates mental tension, which in turn develops into somatic and physical responses such as sweaty palms, shaky legs and lower range of physical capabilities and motion. An important pedagogical task is to induce exploration of how to use different patterns of inter-wall and inter-limb modes of coordination so that these can be efficiently transferred into future learning and performance tasks. To be relevant for climbing, movement patterns during traversal should be adaptive, based on information–movement couplings with changeable characteristics (or some level of uncertainty). These activities should also be undertaken in such a way that the psychological constraints are introduced gradually so that success is probable and psychological constraints do not interfere with the physical learning. At the same time though, the beginner learns to manage potential psychological arousal.

Provided that individuals adapt existing patterns of coordination to perform new tasks, the practitioner can exploit these as a platform to assist the learner to explore new actions. One can expect that learners will be typically attracted to stable states of behavioural organisation, which indicates that existing patterns of coordination need to be challenged so as to induce exploration and subsequently new behaviours. Because in determining the usability of holds, inexperienced climbers may need to explore the graspable properties of the holds, which can occur through visual or haptic exploration, exploration may also induce considerable fatigue. Balancing both fatigue and the need to challenge existing stable patterns can be an important consideration (e.g. rest points can be strategically designed into a route). Collectively, practitioners can induce exploration of different climbing actions through providing individuals access to existing patterns of coordination, but challenging these through constraint manipulation. For example, to facilitate exploration of different movement patterns, holds can be used that allow for a variety of actions, such as horizontal over-hand grips and vertical pinch style grips. Presuming that the over-hand grip is intrinsically stable to inexperienced climbers (i.e. it allows individuals to ‘hang’ their hands over the hold and use their more powerful latissimus dorsi musculature), one can expect that beginners might be able to use this action as a fall back, if when exploring a movement that needs to be learnt becomes too difficult to achieve. In this respect, more extensive exploration can be introduced during traversals through representing variable graspable edges. If successful, multiple actions for traversal should be available to the learner as an individual undertakes multiple attempts, the practitioner can expect variation from trial to trial in what actions are used. Such variability, as we have previously discussed, supports the acquisition and transfer of performance.

In presenting some pilot work in our lab exemplify [61], it has been shown that in a group of low-experienced climbers, using a route design that contains multiple grasping patterns (e.g. horizontal over-hand grips and vertical grasping patterns) at each hold and crux regions into the route, the exploration of the structural properties of holds can be induced. Although this resolves with practice, we saw that use of vertical grasping increased and ratings of the hold usability were significantly increased (Fig. 28.2).

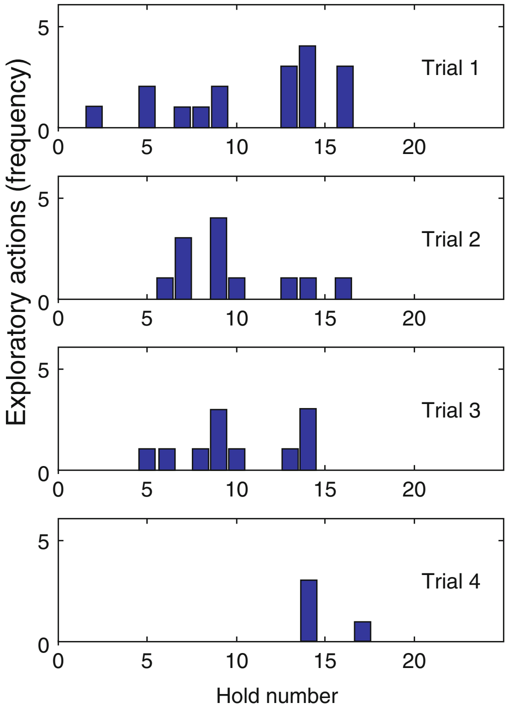

Fig. 28.2 Rate of exploratory actions examined by touching the holds and not using them [61]. In this study, a group of low-experienced climbers (level 5b–5c on the French rate scale of difficulty) climbed four times on a route with holds designed to allow both horizontal over-hand and vertical pinch grips. This combined with the use of crux points designed into the route at holds 7–8 and 13–14 induced exploration (touching the holds). With practice this resolved as the climbers improved their knowledge of how to grasp and use the holds

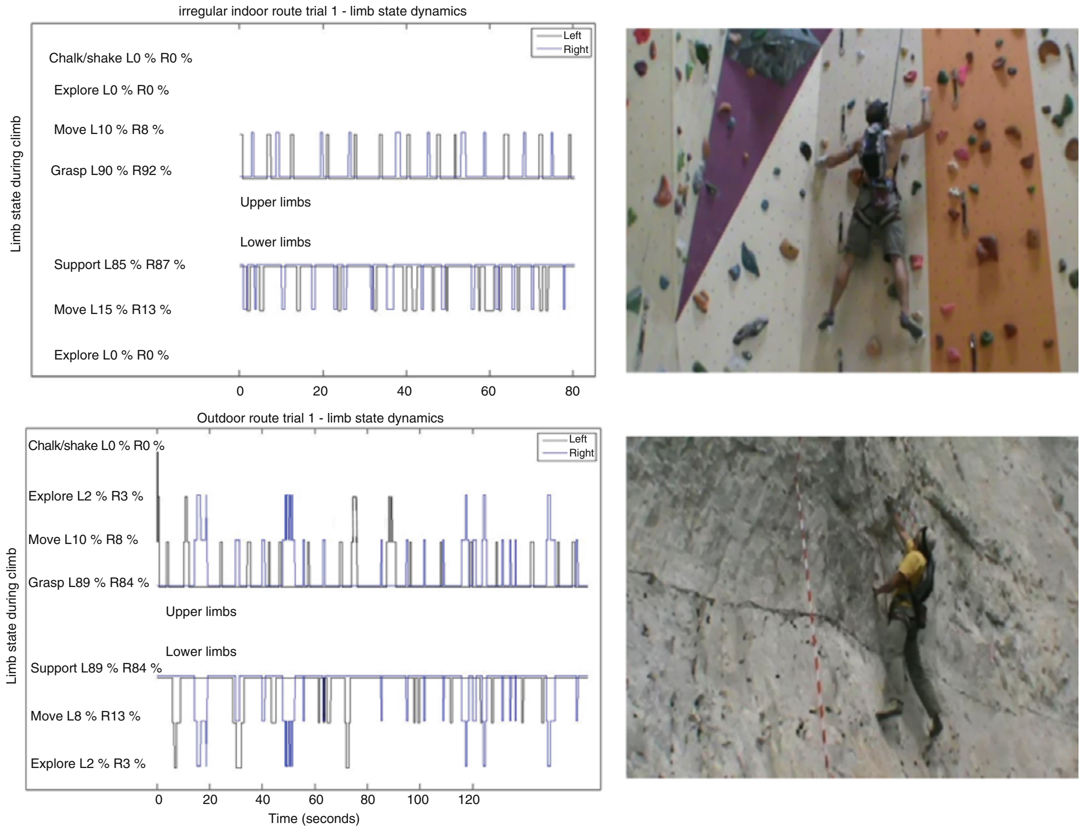

Fig. 28.3 Classification of climbing activities (i.e. support, move, explore) based on video notational analysis. The classification shows individual data for on-sight climbs (6a–6b on the French rate scale of difficulty) in indoor and outdoor. Both climbs contained the same number of holds at the same relative positions and graspability. The lower panel reveals that in the outdoor environment, exploration of holds is naturally induced, whereas in the indoor context, much more regular patterns are observed and in this climber did not need to explore the hold properties during the traverse

In more experienced climbers, one can expect that a variety of movement patterns are already stable, and an important pedagogical task for these individuals might be to meet their specific training goals, such as the transfer of performance to different climbing genres or to achieve an overall improved efficiency in exploration (Fig. 28.1). In presenting additional pilot work (Fig. 28.3), the impact that an outdoor environment has on exploration can be observed in the movement behaviour of each limb. In this study, experienced individuals were asked to climb an indoor and an outdoor route. The indoor route was designed with the holds being placed at the same relative positions and grasp ability with respect to the outdoor route. Here it was observed that experienced climbers (over 6c on the French rate scale of difficulty) were induced to explore hold properties both with their hands and feet. In comparison, very rarely did we observe any exploration during the indoor traverse.

Introducing uncertainty in the usability of holds is highly challenging to the practitioner in the indoor setting because holds are artificial, of the same colour and bolted to a wall often of a different texture and colour to the holds, enhancing their level of contrast. However, the practitioner can creatively draw on an extensive range of constraints. For example, an approach for introducing uncertainty into routes in the indoor environment can be through providing multiple pathways through a route, where the challenge is in determining the most efficient pathway for traversal. In this respect, metastability maybe induced at the level of route finding and allows for variation in behaviour during the route finding process [70].

28.11 Concluding Remarks

In finishing we summarise some of the key pedagogical implications of this review. The role of a coach in climbing has been previously outlined as one whose role is not driven by syllabus content, but by the specific needs of each individual learner [65]. In this chapter, we have conceptualised that, within the ecological dynamics framework, learning can be directed at the scale level of the individual performer and his/her environment. In accounting for individually specific characteristics, determining appropriate methods for inducing exploration of available system degeneracy during emergent performer–environment interactions can promote the generalisability of skill. Natural or emergent variability can be located in the performer–environment relationship via manipulating constraints so that multiple affordances can be functional. This allows the individual to explore available system degeneracy by harnessing self-organising processes. The challenge for the extreme sport practitioner is how to set up opportunities for efficient exploration in a manner that manages the dangers of performing in unpredictable contexts. Representing uncertainty within the relative safety of indoor settings may be one approach for preparing climbers for performance in demanding contexts. This, however, has been argued to depend on the design of constraints in the learning context and the level of uncertainty that they represent.

References

1. Phillips K, Sassaman J, Smoliga J. Optimizing rock climbing performance through sport specific strength and conditioning. Strength Cond J. 2012;34(3):1–18.
2. Moulin C. Solos. Chamonix: Guérin edition; 2005.
3. Child G. Mixed emotions: mountaineering writings. Seattle: Mountaineers Books; 1993.
4. Davids K, Araujo D, Hristovski R, Passos P, Chow JY. Ecological dynamics and motor learning design in sport. In: Hodges NJ, Williams AM, editors. Skill acquisition in sport: research, theory and practice. 2nd ed. New York: Routledge (Taylor and Francis Group); 2012. p. 112–30.
5. Davids K, Button C, Bennett SJ. Dynamics of skill acquisition: a constraints-led approach. Champaign: Human Kinetics; 2008.
6. Davids K, Handford C, Williams AM. The natural physical alternative to cognitive theories of motor behavior: an invitation for interdisciplinary research in sports science? J Sports Sci. 1994;12:495–528.
7. Seifert L, Orth D, Hérault R, Davids K. Metastability in perception and action in rock climbing. In: Passos P, Barreiros J, Cordovil R, Araújo D, Melo F, editors. XVIIth international conference on perception and action. Estoril: FMH Editions, Portugal; 2013.
8. Araújo D, Davids K, Hristovski R. The ecological dynamics of decision making in sport. Psychol Sport Exerc. 2006;7(6):653–76.
9. Gibson J. The ecological approach to visual perception. Boston: Houghton Mifflin; 1979.
10. Kelso JAS. Dynamic patterns: the self-organization of brain and behavior. Cambridge, MA: MIT; 1995.
11. Newell KM. Constraints on the development of coordination. In: Wade MG, Whiting HTA, editors. Motor development in children. Aspects of coordination and control. Dordrecht: Martinus Nijhoff; 1986. p. 341–60.
12. Brunswik E. Representative design and probabilistic theory in a functional psychology. Psychol Rev. 1955;62(3):193–217.
13. Brunswik E. Perception and the representative design of psychological experiments. Berkeley: University of California Press; 1956.
14. Araújo D, Davids K, Passos P. Ecological validity, representative design, and correspondence between experimental task constraints and behavioral setting: comment on Rogers, Kadar, and Costall 2005. Ecol Psychol. 2007;19(1):69–78.
15. Pinder RA, Davids K, Renshaw I, Araújo D. Representative learning design and functionality of research and practice in sport. J Sport Exerc Psychol. 2011;33(1):146–55.
16. Davids K, Araújo D. The concept of "Organismic Asymmetry" in sport science. J Sports Sci. 2010;13(6):633–40.
17. Carroll TJ, Barry B, Riek S, Carson RG. Resistance training enhances the stability of sensorimotor coordination. Proc Biol Sci Roy Soc. 2001;268(1464):221–7.
18. Fawcett T. Mental toughness a phenomenological perspective. In: Gucciardi D, Gordon S, editors. Mental toughness in sport: developments in theory and research. New York: Taylor & Francis Group/Routledge; 2011. p. 9–29.
19. Newell KM, Liu YT. Functions of learning and the acquisition of motor skills (with reference to sport). Open Sports Sci J. 2012;5:17–25.
20. Newell KM. Change in movement and skill: learning, retention and transfer. In: Latash ML, Turvey MT, editors. Dexterity and its development. Mahwah: Erlbaum; 1996. p. 393–430.

21. Issurin V. Training transfer: scientific background and insights for practical application. Sports Med. 2013;43(8):675–94.
22. Rosalie S, Müller S. A model for the transfer of perceptual-motor skill learning in human behaviors. Res Q Exerc Sport. 2012;83(3):413–21.
23. Rosalie S, Müller S. Expertise facilitates the transfer of anticipation skill across domains. Q J Exp Psychol. 2014;67(2):319–34.
24. Moore C, Müller S. Transfer of expert visual anticipation to a similar domain. Q J Exp Psychol. 2014;67(1):186–96.
25. http://www.alainrobert.com/index.en.html.
26. Guinness Book of World Records. 2011.
27. Bourdin C, Teasdale N, Nougier V, Bard C, Fleury M. Postural constraints modify the organization of grasping movements. Hum Mov Sci. 1999;18:87–102.
28. Boschker MSJ, Bakker FC. Inexperienced sport climbers might perceive and utilize new opportunities for action by merely observing a model. Percept Mot Skills. 2002;95(1):3–9.
29. Seifert L, Wattebled L, L'Hermette M, Herault R. Inter-limb coordination variability in ice climbers of different skill level. Educ Phys Train Sport. 2011; 1(80):63–8.
30. Bourdin C, Teasdale N, Nougier V. High postural constraints affect the organization of reaching and grasping movements. Experimental brain research. Experimentelle hirnforschung. Expérimentation Cérébrale. 1998;122(3):253–9.
31. Testa M, Martin L, Debû B. Effects of the type of holds and movement amplitude on postural control associated with a climbing task. Gait Posture. 1999;9(1):57–64.
32. Testa M, Martin L, Debû B. 3D analysis of posturo-kinetic coordination associated with a climbing task in children and teenagers. Neurosci Lett. 2003;336(1):45–9.
33. Seifert L, Wattebled L, Herault R, Poizat G, Adé D, Gal-Petitfaux N, Davids K. Neurobiological degeneracy and affordance perception support functional intra-individual variability of inter-limb coordination during ice climbing. PLoS One. 2014; 9(2):e89865.
34. Seifert L, Wattebled L, L'Hermette M, Bideault G, Herault R, Davids K. Skill transfer, affordances and dexterity in different climbing environments. Hum Mov Sci. 2013;32(6):1339–52.
35. Cordier P, Mendès-France M, Bolon P, Pailhous J. Entropy, degrees of freedom, and free climbing: a thermodynamic study of a complex behavior based on trajectory analysis. Int J Sport Psychol. 1993; 24:370–8.
36. Cordier P, Mendès-France M, Pailhous J, Bolon P. Entropy as a global variable of the learning process. Hum Mov Sci. 1994;13:745–63.
37. Sanchez X, Lambert P, Jones G, Llewellyn DJ. Efficacy of pre-ascent climbing route visual inspection in indoor sport climbing. Scand J Med Sci Sports. 2012;22(1):67–72.
38. Nougier V, Orliaguet JP, Martin O. Kinematic modifications of the manual reaching in climbing: effects of environmental and corporal constraints. Int J Sport Psychol. 1993;24:379–90.
39. Pijpers JR, Oudejans RD, Bakker F, Beek PJ. The role of anxiety in perceiving and realizing affordances. Ecol Psychol. 2006;18(3):131–61.
40. Batoux P, Seifert L. Ice climbing and dry-tooling: from Mont Blanc to Leman. Chamonix: JM Editions; 2007.
41. Blanc-Gras J, Ibarra M. The art of ice climbing. Chamonix: Blue Ice Edition; 2012.
42. Chow JY, Davids K, Hristovski R, Araújo D, Passos P. Nonlinear pedagogy: learning design for self-organizing neurobiological systems. New Ideas Psychol. 2011;29(2):189–200.
43. Warren WH. The dynamics of perception and action. Psychol Rev. 2006;113(2):358–89.
44. Passos P, Araújo D, Davids K, Gouveia L, Milho J, Serpa S. Information-governing dynamics of attacker–defender interactions in youth rugby union. J Sports Sci. 2008;26(13):1421–9.
45. Newell KM, Corcos DM. Variability and motor control. Human kinetics: Champain; 1993.
46. Newell KM, Deutsch KM, Sosnoff JJ, Mayer-Kress G. Variability in motor output as noise: a default and erroneous proposition? In: Davids K, Bennet SJ, Newell KM, editors. Movement system variability. Champaign: Human Kinetics; 2006. p. 3–23.
47. Slifkin AB, Newell KM. Is variability in human performance a reflection of system noise? Curr Dir Psychol Sci. 1998;7(6):170–7.
48. Davids K, Glazier PS, Araújo D, Bartlett RM. Movement systems as dynamical systems: the functional role of variability and its implications for sports medicine. Sports Med. 2003;33(4):245–60.
49. Van Emmerik REA, Van Wegen EEH. On variability and stability in human movement. J Appl Biomech. 2000;16:394–406.
50. Seifert L, Button C, Davids K. Key properties of expert movement systems in sport : an ecological dynamics perspective. Sports Med. 2013;43(3):167–78.
51. Sparrow WA, Newell KM. Metabolic energy expenditure and the regulation of movement economy. Psychon Bull Rev. 1998;5(2):173–96.
52. Edelman GM, Gally J. Degeneracy and complexity in biological systems. Proc Natl Acad Sci U S A. 2001;98(24):13763–8.
53. Mason PH. Degeneracy at multiple levels of complexity. Biol Theory. 2010;5(3):277–88.
54. Davids K, Glazier PS. Deconstructing neurobiological coordination: the role of the biomechanics-motor control nexus. Exerc Sport Sci Rev. 2010;38(2):86–90.
55. Withagen R, Chemero A. Affordances and classification: on the significance of a sidebar in James Gibson's last book. Philos Psychol. 2012;25(4):521–37.
56. Withagen R, De Poel HJ, Araújo D, Pepping GJ. Affordances can invite behavior: reconsidering the relationship between affordances and agency. New Ideas Psychol. 2012;30(2):250–8.

57. Boschker MSJ, Bakker F, Michaels CF. Memory for the functional characteristics of climbing walls: perceiving affordances. J Mot Behav. 2002;34(1): 25–36.
58. Fajen BR, Riley MR, Turvey MT. Information, affordances, and the control of action in sport. Int J Sports Psychol. 2009;40(1):79–107.
59. Jacobs DM, Michaels CF. Direct learning. Ecol Psychol. 2007;19(4):321–49.
60. Sibella F, Frosio I, Schena F, Borghese NA. 3D analysis of the body center of mass in rock climbing. Hum Mov Sci. 2007;26(6):841–52.
61. Seifert L, Orth D, Hérault R, Davids K. Affordances and grasping patterns variability during rock climbing. In: Davis T, Passos P, Dicks M, Weast-Knapp J, editors. Studies in perception and action XII: seventeenth international conference on perception and action. Estoril: Psychology Press/Taylor & Francis; 2013. p. 114–8.
62. Johnson HW. Skill = speed x accuracy x form x adaptability. Percept Mot Skills. 1961;13:163–70.
63. Steck U. Speed. Chamonix: Guérin edition; 2014.
64. Fryer S, Dickson T, Draper N, Eltom M, Stoner L, Blackwell G. The effect of technique and ability on the VO2–heart rate relationship in rock climbing. Sports Technol. 2012;5(3–4):143–50.
65. Pezzulo G, Barca L, Lamberti Bocconi A, Borghi A. When affordances climb into your mind: advantages of motor simulation in a memory task performed by novice and expert rock climbers. Brain Cogn. 2010;73:68–73.
66. Collins L, Collins D. Conceptualizing the adventure-sports coach. J Adventure Educ Outdoor Learn. 2012;12(1):81–93.
67. Fryer S. Physiological and psychological contributions to on-sight rock climbing, and the haemodynamic responses to sustained and intermittent contractions. Christchurch: University of Canterbury; 2013.
68. Fuss F, Niegl G. Instrumented climbing holds and performance analysis in sport climbing. Sports Technol. 2008;1(6):301–13.
69. Sanchez X, Boschker MSJ, Llewellyn DJ. Pre-performance psychological states and performance in an elite climbing competition. Scand J Med Sci Sports. 2010;20(2):356–63.
70. Hardy L, Hutchinson A. Effects of performance anxiety on effort and performance in rock climbing: a test of processing efficiency theory. Anxiety Stress Coping. 2007;20(2):147–61.
71. Seifert L, Coeurjolly J, Hérault R, Wattebled L, Davids K. Temporal dynamics of inter limb coordination in ice climbing revealed through change-point analysis of the geodesic mean of circular data. J Appl Stat. 2013;40(11):2317–31.
72. Brymer E, Hughes T, Collins L. The art of freestyle. Bangor: Pesda Press; 2000.
73. Brymer E, Oades L. Extreme sports: a positive transformation in courage and humility. J Humanist Psychol. 2009;49(1):114–26.
74. Brymer E. Risk and extreme sports: a phenomenological perspective. Ann Leis Res. 2010;13(1,2): 218–39.
75. Brymer E, Davids K. Ecological dynamics as a theoretical framework for development of sustainable behaviours towards the environment. Environ Educ Res. 2013;19(1):45–63.
76. Brymer E, Renshaw I. An introduction to the constraints-led approach to learning in outdoor education. Aust J Outdoor Educ. 2010;14(2):33–41.
77. http://www.outsideonline.com/outdoor-adventure/climbing/rock-climbing/No-StringsAttached.html. Accessed on Dec 2014.

29

Employment of Near-Infrared Spectroscopy to Assess the Physiological Determinants of Hiking Performance in Single-Handed Dinghy Sailors

Ioannis Vogiatzis

29.1 Introduction

Hiking is the effort performed by single-handed dinghy sailors in order to counterbalance their boats in strong winds by placing body weight as far to windward as possible, thereby decreasing the extent of boat heel (Fig. 29.1 top). In hiking, feet are hooked under straps in the boat and the weight is borne, typically about mid-thigh, on the edge of the boat deck; the rest of the body hangs over the water (Fig. 29.1 top).

What makes dinghy hiking a different form of physical activity from what predominates in almost every other sport is the persistent near-isometric contraction of the quadriceps muscles sustained at approximately 40–50 % of quadriceps' maximal voluntary contraction [1, 2]. Hence the quasi-isometric nature of hiking could potentially limit blood flow and thus oxygen availability to quadriceps muscles because of the high intramuscular pressure [3], thereby compromising hiking performance [4, 5].

Earlier studies [5] indicated a progressive decrease in O_2 availability to the quadriceps muscles during hiking, evidenced by progressively decreasing tissue O_2 saturation assessed by near-infrared spectroscopy (NIRS). Reduced O_2 saturation during muscular activity could simply reflect the balance between muscle oxygen delivery and demand [6], and thus, the reduction in quadriceps muscle oxygenation reported during hiking [5] could be attributable either to restricted tissue oxygen delivery, increased tissue oxygen demand, or both. Accordingly, the major challenge when studying the limiting factors to hiking performance is whether reduced quadriceps muscle O_2 saturation is due to blood flow restriction. In this context, determination of the extent to which blood flow to quadriceps muscles is limited during hiking has recently been feasible by the employment of NIRS technology in combination with the light absorbing tracer indocyanine green dye (ICG). This is a relatively new and minimally invasive technique for measuring muscle blood flow during hiking.

29.2 Measurement of Quadriceps Muscle Blood Flow by NIRS

Approximately a decade ago, a technique combining NIRS with ICG was developed to measure muscle blood flow by applying the Fick's principle [7]. Indocyanine green dye is a water-soluble tricarbocyanine, light absorbing dye with a peak absorption in human blood in the NIR range of 800 nm. It has been used routinely for measuring cardiac output, as well as limb blood flow with use

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Fig. 29.1 *Top*: on-water hiking on a laser dinghy boat. *Bottom*: simulated hiking on a laser bench (simulator) in the laboratory

of photodensitometry. After intravascular injection, ICG is predominantly bound to albumin and circulates to the right heart and lungs and emerges into the arterial circulation. Arterial blood withdrawn by a pump, and the ICG is recorded by photodensitometry, whereas downstream in the tissue microcirculation, ICG accumulation is detected by measuring light attenuation with NIRS (Fig. 29.2).

Muscle blood flow measurement requires arterial cannulation and continues withdrawal of blood through a photodensitometer for several seconds after injection. Furthermore, one needs to consider that arterial cannulation is associated with the potential risks of bleeding, vascular perforation, vascular insufficiency, and injury to adjusted nerves. Considering the above situation and the fact that the equipment for constant rate blood withdrawal and measurements of ICG may not be available, the NIRS-ICG technique is not feasible in all conditions. For the above reasons, an alternative algorithm has been proposed to calculate tissue perfusion from the NIRS data, namely, the blood flow index (BFI) [8].

Specifically, the BFI is calculated by dividing the ICG peak concentration by the rise time from 10 to 90 % of peak (Fig. 29.3) [8].

In addition, the BFI is derived only from the transcutaneously measured NIRS-ICG curve and not from the arterial ICG curve. Thus, the only invasive component of this technique is venous cannulation for bolus injection of the ICG tracer. For that reason, the BFI is a relative measure of blood flow, as absolute flow cannot be determined unless arterial ICG concentration is measured. BFI has traditionally been used for the assessment of cerebral blood flow [9]. Recently, this method has been validated in human's locomotor and respiratory muscles [8]. Furthermore, in a retrospective analysis, Habazettl and colleagues [8] compared BFI values within the vastus lateralis against absolute muscle blood flow determined using NIRS-ICG technique during cycling exercise at different intensities. The results indicated a very good agreement between BFI and NIRS-ICG technique measured both in respiratory and quadriceps muscles [8].

29.3 Simulated Hiking Experimental Protocol

Each sailor initially completed three successive 3 min hiking bouts, separated by 5 s rest intervals to simulate tacking on a laser simulator (Fig. 29.1 bottom) [4, 5]. After the completion of the three hiking bouts, each sailor underwent three constant-intensity exercise tests during which the intensity of exercise was adjusted to reach and maintain the mean cardiac output recorded during each of the three hiking bouts. Muscle blood flow and oxygen availability in vastus lateralis muscle were simultaneously assessed in six laser class sailors during successive hiking and cycling bouts sustained at equivalent cardiac outputs recorded by impedance cardiography. It was reasoned that if at such equivalence both muscle blood flow and tissue oxygen availability in vastus lateralis muscle were lower during hiking compared to cycling, this would indicate that quadriceps muscle blood flow restriction is the principal limitation on

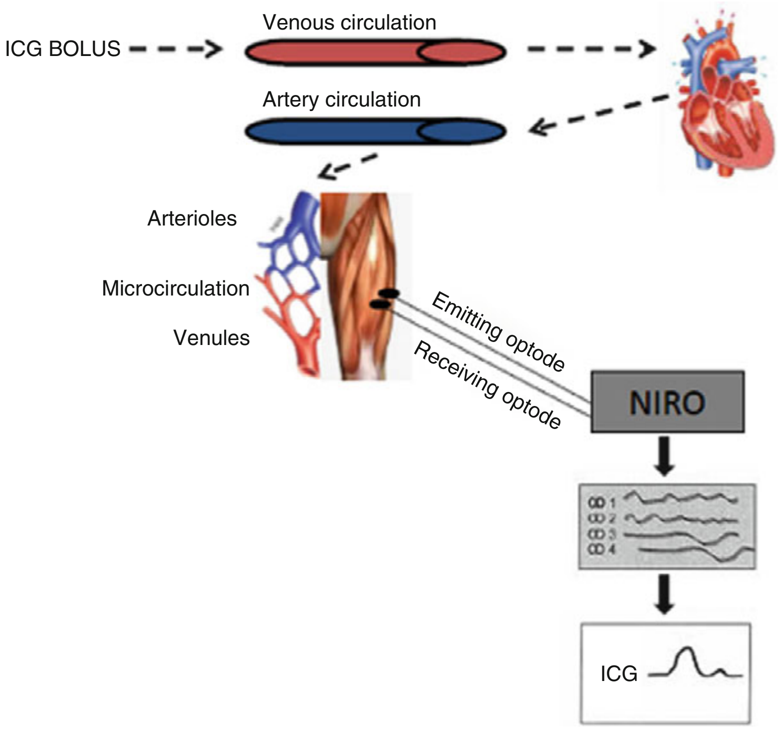

Fig. 29.2 Schematic representation of the NIRS measurements of indocyanine green (ICG) in tissue after a venous bolus infusion. From top left, an ICG bolus is injected into the venous circulation; it passes through the heart and lungs and into the arterial circulation and microcirculation. The NIRS optodes positioned over the tissue detect the ICG at several wavelengths, and, by use of specific extinction coefficients in a matrix operation, the ICG curve is isolated. The circles represent the vessels from which the NIRS is detected

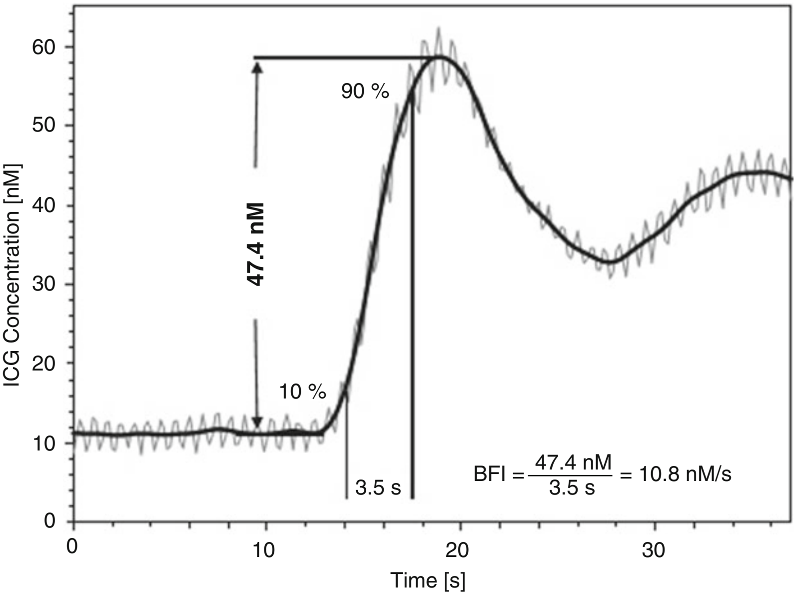

Fig. 29.3 Typical example of quadriceps muscle indocyanine green (ICG) concentration curve recorded by near-infrared spectroscopy (NIRS) during exercise at 30 % limit of tolerance. The original tracing (*gray line*) appears with marked oscillations (at a frequency of 84/min; 1.4 Hz) owing to muscle contraction and relaxation during cycling. Low-pass filtering with a cutoff frequency of 0.5 Hz produced the smoothed curve (*black line*) that was used for blood flow index (BFI) calculation. Data points at 10 and 90 % of ICG concentration peak are indicated, and an example of BFI calculation is given

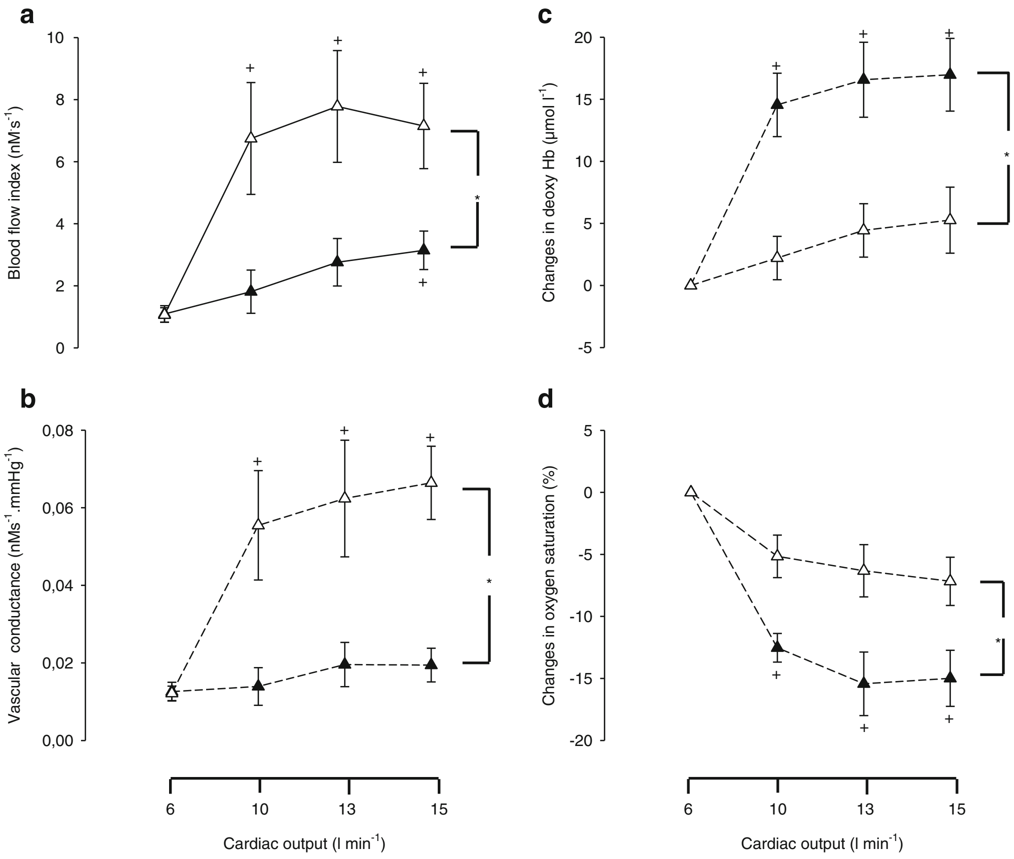

Fig. 29.4 Quadriceps muscle blood flow index (**a**), vascular conductance (**b**), deoxyhemoglobin (Hb) concentration (**c**), and oxygen saturation (**d**) during hiking (*closed symbols*) and cycling (*open symbols*). Data are shown relative to the mean (± S.D) cardiac output recorded during the three hiking bouts that was reproduced during cycling. Data are expressed as mean ± S.D. Asterisks denote significant differences between the two conditions, whereas crosses denote significant differences compared to the values at rest

quadriceps muscle oxygen delivery and thus tissue oxygen availability. Under such circumstances, the magnitude of this restriction could be quantified relative to the unobstructed quadriceps muscle perfusion during cycling.

29.4 Findings

Figure 29.4a displays changes from baseline in blood flow index for vastus lateralis during cycling and across the three hiking bouts as a function of a given range in cardiac output [10].

The increase from baseline in vastus lateralis muscle blood flow index during the constant-intensity cycling exercise test (Fig. 29.4a) was three- to fourfold greater compared to that recorded during the three hiking bouts. In addition, vastus lateralis muscle vascular conductance was significantly lower during hiking compared to cycling (Fig. 29.4b). Deoxyhemoglobin concentration was greater (Fig. 29.4c) and oxygen saturation was lower (Fig. 29.4d) during hiking compared to cycling, thereby indicating reduced quadriceps muscle O_2 availability during hiking.

29.5 Conclusions and Implications

Quadriceps muscle blood flow and oxygen saturation were shown to be threefold lower compared to cycling sustained at similar recordings of cardiac output [10]. It is thus suggested that the progressive reduction in quadriceps muscle oxygen availability during hiking is attributable to reduced blood flow to these muscles [10]. These findings have important implications for sailing since they demonstrate that the quasi-isometric nature of activity of vastus lateralis muscles during dingy hiking is responsible for the reduced blood flow and oxygen availability to these muscles.

As with dynamic exercise, quadriceps muscle isometric contractions during hiking can be endured continuously even in the presence of reduced muscle blood flow and oxygen availability by the introduction of intervals of muscle relaxation between the bouts of sustained isometric contractions. Thus, it is suggested that an intermittent nature of hiking will allow sailors to perform this physically challenging effort for several minutes during competitive sailing in two or even three races per day. Accordingly, during hiking, sailors should continuously adjust boat trim by fore and aft body movements so as to allow momentary relaxation of the lower limbs, thus promoting greater muscle perfusion.

In conclusion, it is suggested that during hiking there is a restriction in blood flow and oxygen availability to quadriceps muscles that most likely leads to energy deficits and onset of muscle fatigue. Accordingly, sailors should continuously perform small lower body movements during hiking so as to allow momentary relaxation of the lower limbs, thus promoting greater muscle perfusion and oxygen delivery. Practice on a hiking bench, similar to the one shown in Fig. 29.1, will facilitate sailors to determine their own individualized intermittent pattern of quadriceps isometric muscle performance.

References

1. Vogiatzis I, Spurway NC, Wilson J, Boreham C. Assessment of aerobic and anaerobic demands of dinghy sailing at different wind velocities. J Sport Med Phys Fitness. 1995;35:103–7.
2. Spurway NC. Hiking physiology and the “quasi-isometric” concept. J Sports Sci. 2007;25:1081–93.
3. Lind A. Cardiovascular adjustments to isometric contractions: static effort. In Handbook of Physiology. Cardiovasc Syst. 1983;3:947–66.
4. Vogiatzis I, Spurway NC, Jennett S, Wilson J, Sinclair J. Changes in ventilation related to changes in electromyograph activity during repetitive bouts of isometric exercise in simulated sailing. Eur J Appl Physiol Occup Physiol. 1996;72:195–203.
5. Vogiatzis I, Tzineris D, Athanasopoulos D, Georgiadou O, Geladas N. Quadriceps oxygenation during isometric exercise in sailing. Int J Sports Med. 2008;29:11–5.
6. Chance B, Dait MT, Zhang C, Hamaoka T, Hagerman F. Recovery from exercise-induced desaturation in the quadriceps muscles of elite competitive rowers. Am J Physiol. 1992;262:766–75.
7. Boushel R, Langberg H, Green S, Skovgaard D, Bulow J, Kjaer M. Blood flow and oxygenation in peritendinous tissue and calf muscle during dynamic exercise in humans. J Physiol. 2000;524:305–13.
8. Habazettl H, Athanasopoulos D, Kuebler WM, Wagner H, Roussos C, Wagner PD, Ungruhe J, Zakynthinos S, Vogiatzis I. Near-infrared spectroscopy and indocyanine green derived blood flow index for noninvasive measurement of muscle perfusion during exercise. J App Physiol. 2010;108:962–7.
9. Wagner BP, Gertsch S, Ammann RA, Pfenninger J. Reproducibility of the blood flow index as noninvasive, bedside estimation of cerebral blood flow. Intensive Care Med. 2003;29:196–200.
10. Vogiatzis I, Andrianopoulos V, Louvaris Z, Cherouveim E, Spetsioti S, Vasilopoulou M, Athanasopoulos D. Quadriceps muscle blood flow and oxygen availability during repetitive bouts of isometric exercise in simulated sailing. J Sports Sci. 2011;29(10):1041–9.

Whole-Body Vibration in Extreme Sports

30

Marco Tarabini and Marco Valsecchi

30.1 Introduction

The effects of vibrations on the human body have been studied and documented for several years, showing both mechanical and psychological effects [1, 2]. Vibration leads to both voluntary and reflex muscle contractions, thus reducing motor performance capabilities and causing local muscle fatigue, particularly when the vibration is at the resonant-frequency of specific body parts. Vibrations can also influence the state of consciousness and induce psychological stress reactions. All these effects may be relevant for those who practise extreme sports; however, the most immediate health consequence of whole-body vibration exposure could be the occurrence of mechanical damage to human tissue.

Several studies [3–7] showed that prolonged or severe exposure to vibration and shocks may lead to low-back pain or to early spine degenerative pathologies, mainly because the vibration induces mechanical stress on the vertebrae and discs, with incidence on the lumbar, thoracic and cervical parts of the column [7]. Back pathologies are also common in the practice of extreme sports, and different studies [8–18] have focused on the possible correlation between back pain and the practice of alpine skiing [8, 12], kite surfing [9–12], snowboarding [12, 14], cycling [12, 16, 18] and triathlon [17], kayaking [19, 20], rafting [21], windsurfing [22–24] and sailing [25].

To date, the correlation between back pathologies and the practice of sports with high vibration exposure is still unclear. Recently we found [12] that the vibration exposure in kitesurfing, snowboarding, skiing and cycling is greater than the maximum vibration exposure permitted for workers as per EU regulations [26]. The whole-body vibration exposure in these four sports, computed in accordance with the ISO 2631 standard [27], ranged between 3 and 9 m/s^2, i.e. from 2.5 to 7 times larger than the exposure limit value for workers (1.15 m/s^2). Since the ISO 2631 standard is not meant to be used in sport activities, the metrics for the quantification of the health risks might not be appropriate; nevertheless, the adoption of different criteria (maximum transient vibration value, vibration dose value and non-weighted vibration level) always evidenced large vibration levels, with probable and considerable health risks for athletes.

Despite the exposure to high levels of vibration, the incidence of back pathologies among alpine skiers, runners, soccer players, weightlifters and shooters does not seem to be frequent [8, 28]. In particular, Peacock et al. studied the prevalence of low-back pain among alpine ski instructors; results evidenced that the lifetime prevalence of back pain among skiers was

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Table 30.1 Vibration exposure in extreme sports evaluated in accordance with the ISO 2631

	Dominant axis	a_w [m/s^2]	MTVV$_z$ [m/s^2]	MTVV/a_w	VDV$_z$ [m/s$^{1.75}$]
Kitesurf	Z	5.5	25	4.5	65 (1 h)
Alpine ski	Z	8.9	100	11	95 (2 h)
Snowboard	Z	6.1	250	41	210 (2 h)

comparable to that of the general population but greater than that of athletes practising other sports.

Videman et al. [28] studied the effect of long-term exercise (runners, soccer players, endurance athletes and shooters) on degenerative pathologies of the back. Also in this case, results showed that odds ratios for back pain were lower among athletes than among control subjects. This outlines that, in general, the physical activity has a positive effect on the back degenerative pathologies, in spite of the presence of shocks implying mechanical stress on the column. The main reason is probably the subject posture: the upper body posture affects the preload on the intervertebral discs, and it is known [3] that awkward posture combined with large vibration exposure increases the back pain risk. The legs' posture affects the apparent mass of the body in standing [29, 30] and sitting posture [31] and varies therefore the vibration reaching the different body parts. The importance of the legs posture on the vibration reaching the spine was confirmed by Rohlmann et al. in [32]: in their study, authors measured in vivo the stress deriving from whole-body vibration (WBV) on the intervertebral discs, by implanting instrumented vertebrae in five subjects. Tests were performed exposing the patients to WBV of different magnitudes and frequencies, upon varying the knees flexure. Results showed that the measured forces decreased by flexing the knees and increased passing from the pivotal rotation of the plate to the plate translation. Unexpectedly, the effect of the vibration amplitude was marginal.

In this chapter, after summarizing the vibration exposure in three sports characterized by standing posture with flexed knees (skiing, snowboarding and kitesurfing), we analyse the vibration transmissibility in different body segments. As in the majority of the existing studies, the biomechanical response has been identified imposing the vibration with a shaker along the vertical axis, similar to what was done in Ref. [31, 33, 34]. The importance of the posture has been already evidenced in the literature [30, 31, 34, 35], but differences may arise as consequence of the particular adopted posture (kitesurfing, snowboarding) or from the particular equipment (alpine ski – ski boots).

30.2 Vibration Exposure

The WBV exposure in kitesurfing, alpine ski and snowboard has been evaluated by Tarabini et al. [12]; the different metrics indicated by the ISO 2631 are summarized in Table 30.1: values are the average of the 2 feet.

Results outline that the dominant vibration is always the vertical one; the weighted accelerations are at least 5 times larger than the limits of the EU legislation. The MTVV/a_w ratio always exceeds the ratio 1.5 suggested by the standard (values between 4.5 and 41), outlining the presence of impulsive events (jumps in snowboarding and kitesurfing, snow irregularities in skiing). Also the vibration dose value (VDV) largely exceeds the EU regulation limit (21 m/s$^{1.75}$).

Additional analyses proved that the vibration distribution at the feet is not uniform. In kitesurfing, the low-frequency roll, pitch and yaw of the board (whose behaviour is rigid in the frequency range of interest for WBV) entail a different exposure of the bow and stern feet. The stern (flexed) leg mainly supports the kitesurfer weight; at the rear pad location, the average vibration level of the table is relatively low (2.39 m/s^2). The bow (straight) leg does not support the static weight of the subject, but the vibration level at the bow pad is larger than 15 m/s^2 at the forefoot. The centre of rotation of the board is behind the stern leg, and consequently the two legs move in phase. At the current state of the art, it is not possible to predict

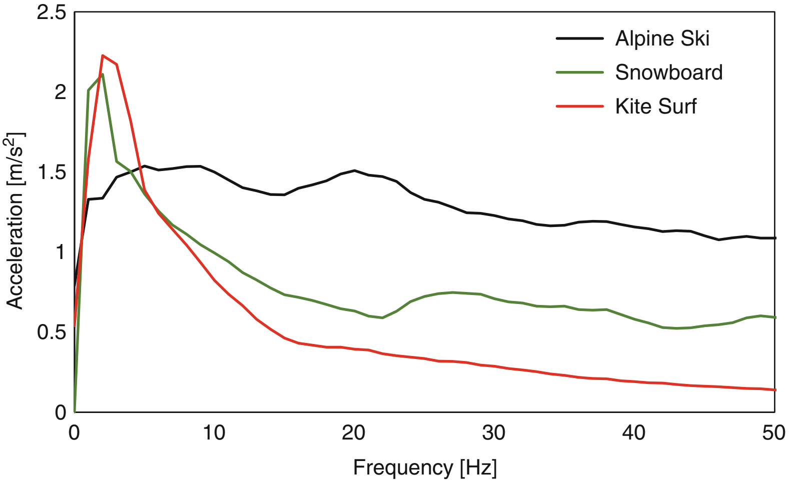

Fig. 30.1 Averaged vibration spectra (*Z* axis) in skiing, snowboarding and kitesurfing

the stress on the intervertebral discs, but the studies of Rohlman et al. [36] indicated the importance of the phase difference between the vibrations at the feet on the bending moments on the vertebrae.

In alpine ski, the vibration exposure of the feet is symmetrical, given that no differences were noticed between the left and right ski (differences smaller than 0.2 m/s^2). Nevertheless, during turns, both the vibration exposure and load on the 2 feet are different (the majority of the load is carried by the internal ski). The vibration at the rearfoot was averagely 20 % larger than that at the forefoot. The acceleration, measured in proximity of the ski binding, outlined that the motion is the superposition of a vertical vibration and a rotation along the Y (lateral) axis. The rotation leads to a fore-and-aft motion of the upper part of the body.

In snowboarding, the vibration on the fore leg is larger than that on the aft leg [37]. The vibration level increases with the speed [12] and depends on the snow conditions [37]. The vibration during the turns is 3–5 times larger than the vibration in straight trajectories. The maximum transient vibration level was the largest among the investigated conditions and was reached in jumps and other evolutions in a snow park.

Given that the vibration transmissibility between the body segments depends on the frequency, the spectral analysis adds useful information to the mere vibration levels presented in the previous section. The vibration at the feet does not show dominant frequency components: the averaged spectra in Fig. 30.1 summarize 30 min of measurements in alpine skiing, snowboarding and kitesurfing. Data are averaged in order to obtain a frequency resolution of 1 Hz; in case of alpine ski and snowboard, data are the average of the four vertical accelerometers placed at the tip and at the toe of the 2 feet; in case of kitesurf, the acceleration is directly measured on the central part of the board.

The vibration spectrum in alpine skiing ranges between 1 and 1.5 m/s^2 up to 50 Hz. The vibration spectra in kitesurfing and snowboarding decrease above 5 Hz, reasonably because of the larger compliance of the boards with respect of the ski. As outlined in the literature [38, 39], the effect of the snow and water conditions on the vibration is important, but is generally low in comparison with the effect of the speed.

30.3 Biomechanical Response

The biomechanical response of the human body to vibration is commonly expressed by the vibration transmissibility and by the apparent mass. The vibration transmissibility is the frequency response function between the vibrations at two positions (the stimulus is often at the driving

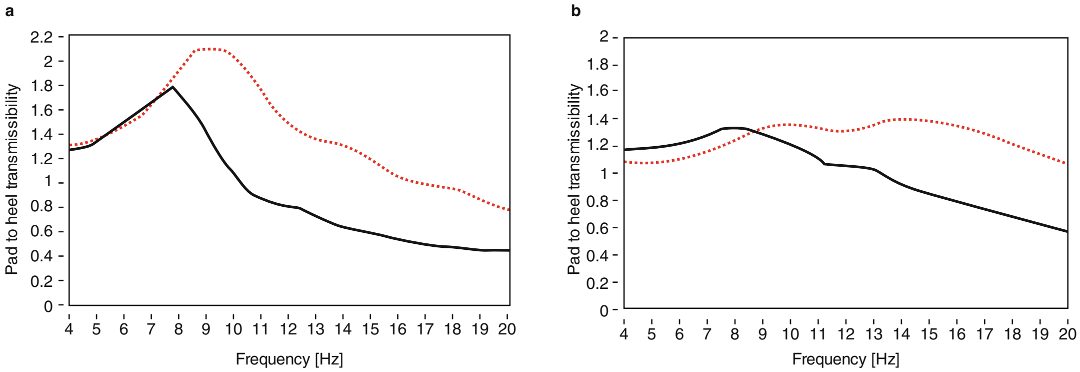

Fig. 30.2 Vibration transmissibility from the kitesurf board to the subject heel on two different boards (plots **a** and **b**) and in different postures (*black line*: standing posture, *red dotted line*: kitesurf posture)

point, and the response location varies depending on the application). The apparent mass is defined as the ratio between the inertial force that a subject transmits to the supporting interface and the acceleration of the interface itself.

The biomechanical responses of standing subjects (apparent mass and transmissibility) have been extensively studied with subjects standing over rigid plates with barefoot or shoes. Nevertheless, the sport equipment can modify both the vibration transmissibility along the human body and the apparent mass. To our knowledge, there are only two studies [38, 39] focused on the identification of the vibration transmissibility using sports equipment.

The vibration transmissibility in kitesurfing has been studied in Ref. [39] with two subjects (body masses 64 and 80 kg, 1.72 and 1.78 m tall, respectively) standing on two different boards. The transmission of vibration to the body is affected by the presence of the board pads; consequently, studies were performed to evaluate the transmissibility from the board to the heel. Results (summarized in Fig. 30.2) showed that the transmissibility in kitesurfing posture (weight on the stern leg) is different from the one of subjects standing on the board in a balanced position. The mechanisms of vibration transmission to the remaining parts of the body are therefore expected to be different from those of the standing subjects.

A similar issue was evidenced for alpine skiing, in the analysis of vibration transmissibility from the supporting surface to the third lumbar vertebra with and without the skis [39]. Results (Fig. 30.3) show that the ski boots increase the amplification of the main resonance of the upper body from 2 to 2.5; the amplification at the second resonance frequency decreases from 1 to 0.35. Also in this case, the mechanisms of vibration transmission are expected to be totally different from those of standing subjects.

30.4 Discussion and Conclusions

To date, the effect of whole-body vibration on the aetiology of back pathologies in extreme sports is not clear. WBV has documented positive effects: it improves the muscle strength, the bone density, the blood flow and the mobility [32]. Nevertheless, the continuous exposure to WBV increases the possibility of back degenerative pathologies [2–7] mainly because of the stress induced by the acceleration on the spine. A weak correlation between the vibration amplitude and the stress on the intervertebral discs has been proven by the studies performed by Rohlman et al., in vivo [31], and the extremely large vibration levels experienced by kitesurfers, snowboarders and alpine skiers have been documented by Tarabini et al. [12]. The stress on the spine is surely affected by the particular postures assumed in the extreme sports. The knee flexion, in particular, largely reduces the amount of vibration reaching the trunk, but the adoption of a nonsymmetrical

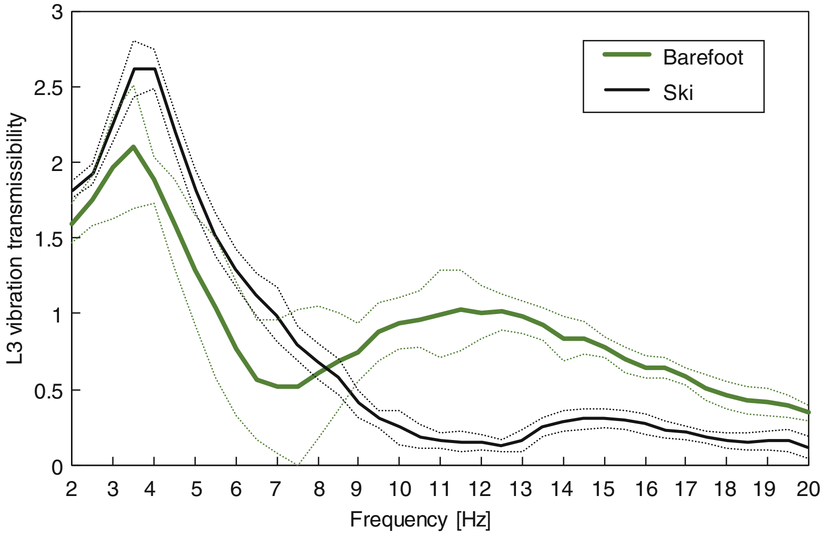

Fig. 30.3 Effect of the skis on the transmissibility between the feet and the L3 lumbar vertebra

posture, paired with tilting motion of the feet supports, induces bending moment on the spine that is balanced with an increase of compression on one part of the intervertebral disc.

The lack of studies focused on the prevalence of spine pathologies in extreme sports prevents from stating if the positive effects of WBV are larger or smaller than the negative ones. The effect of the posture was proven important, and consequently, the benefits deriving from the general studies of WBV are limited. The forthcoming studies should focus on different issues. First of all, the metrics used to quantify the WBV exposure indicated in the ISO 2631 (meant to quantify the risk of sitting and standing workers) lead to an overestimation of the risk, given that the EU regulation limits are always exceeded without a clear prevalence of WBV pathologies in subjects practising the aforementioned sports. The known importance of posture on the forces acting on the vertebrae [32] should be taken into account in the definition of the new procedures for the evaluation of risks deriving from WBV. In particular, it seems reasonable to adopt different metrics (or different limits) for the quantification of risk in standing and sitting posture and in presence of up and down vibration or seesaw vibration.

The adoption of nonsymmetrical postures with flexed knees increases the mechanical stresses on the lower limbs. The most common type of injury for skiers is the anterior cruciate ligament sprain [40], while among snowboarders, wrist, shoulder and ankle injuries are more common. Among kitesurfers, acute injuries are more common than the chronic ones [11], and the most common injuries occur in the lower extremities (ankle, foot, knee and lower leg in order of importance [41]). The prevalence of knee injuries in kitesurfing and skiing is larger than that occurring in snowboard, reasonably because in kitesurfing and skiing, static and dynamic forces are mainly supported by one leg at a time.

Other studies are necessary to identify the mechanical and physiological stresses generating the injuries related to WBV in sports. The identification of the vibration characteristics is of paramount importance for using the large amount of data existing in the literature describing the response of the human body to WBV, but the peculiar posture adopted in extreme sports may limit the usability of the existing studies. Biomechanical and physiological measurements on the water and on the snow are compulsory to optimize the sport medical research in these disciplines.

References

1. Griffin M. Handbook of human vibration. London: Academic Press Inc; 1990.
2. Torvinen S, Kannus P, Sievänen H, Järvinen TA, Pasanen M, Kontulainen S, Nenonen A, Järvinen TL, Paakkala T, Järvinen M, Vuori I. Effect of 8-month vertical whole body vibration on bone, muscle performance, and body balance: a randomized controlled study. J Bone Miner Res. 2003;18:876–84. doi:10.1359/jbmr.2003.18.5.876.
3. Bovenzi M, Schust M, Menzel G, Hofmann J, Hinz B. A cohort study of sciatic pain and measures of internal spinal load in professional drivers. Ergonomics. 2014;58(7):1088–102.
4. Bovenzi M. A longitudinal study of low back pain and daily vibration exposure in professional drivers. Ind Health. 2010;48:584–95.
5. Bovenzi M, Hulshof CTJ. An updated review of epidemiologic studies on the relationship between exposure to whole-body vibration and low back pain. J Sound Vib. 1998;215:595–611.
6. Gallais L, Griffin MJ. Low back pain in car drivers: a review of studies published 1975 to 2005. J Sound Vib. 2006;298:499–513.
7. Seidel H. On the relationship between whole-body vibration exposure and spinal health risk. Ind Health. 2005;43:361–77.
8. Peacock N, Walker JA, Fogg R, Dudley K. Prevalence of low back pain in alpine ski instructors. J Orthop Sports Phys Ther. 2005;35:106–10.
9. Lundgren L, Brorsson S, Hilliges M, Osvalder A. Sport performance and perceived musculoskeletal stress, pain and discomfort in kitesurfing. Int J Perform Anal Sport. 2011;11:142–58.
10. Lundgren L, Brorsson S, Osvalder A. Comfort aspects important for the performance and safety of kitesurfing. Work J Preven Assessm Rehabil. 2012;41: 1221–5.
11. Bourgois JG, Boone J, Callewaert M, Tipton MJ, Tallir IB. Biomechanical and physiological demands of kitesurfing and epidemiology of injury among kitesurfers. Sports Med. 2014;44:55–66.
12. Tarabini M, Saggin B, Scaccabarozzi D. Whole-body vibration exposure in sport: four relevant cases. Ergonomics. 2014;58(7):1143–50.
13. Cardinale M, Wakeling J. Whole body vibration exercise: are vibrations good for you? Br J Sports Med. 2005;39:585–9.
14. Floyd T. Alpine skiing, snowboarding, and spinal trauma. Arch Orthop Trauma Surg. 2001;121:433–6.
15. Dimmick S, Brazier D, Wilson P, Anderson SE. Injuries of the spine sustained whilst surfboard riding. Emerg Radiol. 2013;20:25–31.
16. Asplund C, Webb C, Barkdull T. Neck and back pain in bicycling. Curr Sports Med Rep. 2005;4:271–4.
17. Manninen J, Kallinen M. Low back pain and other overuse injuries in a group of Japanese triathletes. Br J Sports Med. 1996;30:134–9.
18. Srinivasan J, Balasubramanian V. Low back pain and muscle fatigue due to road cycling – an sEMG study. J Bodywork Movement Ther. 2007;11:260–6.
19. Edwards A. Injuries in kayaking. Sport Health. 1993;11:8–11.
20. Kameyama O, Shibano K, Kawakita H, Ogawa R, Kumamoto M. Medical check of competitive canoeists. J Ortho Sci. 1999;4(4):243–9.
21. Jackson DM, Verscheure SK. Back pain in whitewater rafting guides. Wilderness Environ Med. 2006;17(3): 162–70.
22. Allen GD, Locke S. Training activities, competitive histories and injury profiles of elite boardsailing athletes. Aust J Med Sci Sports. 1989;21:12–4.
23. Ullis KC, Anno K. Injuries of competitive board sailors. Physicians Sports Med. 1984;12:86–93.
24. Locke S, Allen GD. Etiology of low back pain in elite boardsailors. Med Sci Sports Exerc. 1992;24(9):964–6.
25. Allen JB. Sports medicine and sailing. Phys Med Rehabil Clin N Am. 1999;10(1):49–65.
26. European Parliament and the Council. On the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration). Off J Eur Comm. 2002; L 117/13, 6.7.2002; 2002/44/EC.
27. International Organization for Standardization. ISO 2631: Mechanical vibration: evaluation of human exposure to whole-body vibration, Geneva, Switzerland; 1997. http://www.iso.org/iso/catalogue_detail.htm?csnumber=7612.
28. Videman T, Sarna S, Battié MC, Koskinen S, Gill K, Paananen H, Gibbons L. The long-term effects of physical loading and exercise lifestyles on back-related symptoms, disability, and spinal pathology among men. Spine. 1995;20:699–709.
29. Tarabini M, Solbiati S, Moschioni G, Saggin B, Scaccabarozzi D. Analysis of non-linear response of the human body to vertical whole-body vibration. Ergonomics. 2014;57(11):1711–23.
30. Subashi GHMJ, Matsumoto Y, Griffin MJ. Apparent mass and cross-axis apparent mass of standing subjects during exposure to vertical whole-body vibration. J Sound Vib. 2006;29(35/30):78–95.
31. Rakheja S, Dong RG, Patra S, Boileau P, Marcotte P, Warren C. Biodynamics of the human body under whole-body vibration: synthesis of the reported data. Int J Ind Ergonomics. 2010;40(11):710–32.
32. Rohlmann A, Schmidt H, Gast U, Kutzner I, Damm P, Bergmann G. In vivo measurements of the effect of whole body vibration on spinal loads. Eur Spine J. 2014;23:666–72.
33. Matsumoto Y, Griffin MJ. Mathematical models for the apparent masses of standing subjects exposed to vertical whole-body vibration. J Sound Vib. 2003;260:431–51.
34. Tarabini M, Saggin B, Scaccabarozzi D, Gaviraghi D, Moschioni G. Apparent mass distribution at the feet of standing subjects exposed to whole-body vibration. Ergonomics. 2013;04(03/20):1–14.

35. Subashi GHMJ, Matsumoto Y, Griffin MJ. Modelling resonances of the standing body exposed to vertical whole-body vibration: Effects of posture. J Sound Vib. 2008;317:400–18.
36. Rohlmann A, Hinz B, Blüthner R, Graichen F, Bergmann G. Loads on a spinal implant measured in vivo during whole-body vibration. Eur Spine J. 2010;19:1129–35.
37. Foss GC, Glenne B. Reducing on-snow vibrations of skis and snowboards. Sound Vib. 2007;41:22–7.
38. Cassani G, Della Moretta C. Whole body vibration nello sport. Politecnico di Milano; 2013. https://www.politesi.polimi.it/handle/10589/81291.
39. Valsecchi M. Whole body vibration in kitesurfing politecnico di milano; 2010. https://www.politesi.polimi.it/handle/10589/8162.
40. Kim S, Endres NK, Johnson RJ, Ettlinger CF, Shealy JE. Snowboarding injuries: trends over time and comparisons with alpine skiing injuries. Am J Sports Med. 2012;40:770–6.
41. Pérez-Turpin J, Cortell-Tormo J, Suarez-Llorca C, Jove-Tossi M, Andreu-Cabrera E, Carrasco-Embuena V. Lesiones en kitesurfistas de élite masculinos. Injuries in elite male kitesurfers. Retos Nuevas tendencias en Educación Fisica, Deporte y Recreación. 2011;20:30–2.

31

Physiology and Risk Management of Cold Exposure

Alan Ruddock

31.1 Introduction

Human body temperature limits are asymmetrical, with 5 °C increase from a homeostatic set point of 37 °C causing potentially life-threatening *hyper*thermia and 10 °C decrease causing life-threatening *hypo*thermia. The reason for this asymmetry is unclear, but it might be related to a metabolic Q^{10} effect that accompanies an increase in cellular temperature. Despite controlled endothermy, thermoregulation is principally constrained by environmental biophysics; however, technological advancements in clothing and external heating mechanisms have increased our ability to inhabit cold environments. Yet our innate behavioural reflexes to cold exposure, increasing physical activity, seeking warmer climates and autonomic reflexes of cutaneous vasoconstriction, catecholamine secretion, fluid shifts and shivering thermogenesis, have remained intact since early humanoids evolved. The intensity of these responses is dependent upon the imposed cold stress determined by environmental conditions, body composition and morphology, gender, age and intensity of exercise. Extreme sports often take place in cold environments that challenge human thermoregulation. These demands frequently impair performance and in some instances require medical intervention. It is not uncommon for confusion, disorientation and amnesia to occur at the point of mild hypothermia (35 °C). In these circumstances it is imperative that informed decisions are made regarding the suitability of the event and environmental conditions. Individuals exposed to the cold should be monitored appropriately using a combination of physiological, perceptual and visual methods to identify at-risk individuals. When preventative measures fail, athletes should seek medical attention immediately. This chapter will review the evidence for the evolution of a homeostatic set point of body temperature and the physiological responses associated with maintaining this temperature during exercise in cold environments. Furthermore, guidelines regarding safe environmental conditions and monitoring methods will be presented to provide the reader with an informed overview of the risks associated with exercise during cold exposure.

31.2 Evolution of Homeostatic Set Point

An attempt to maintain body temperature close to 37 °C or at least achieve thermal equilibrium is a physiological and biotechnological challenge. The maintenance of this value is so important that a large integrative physiological response is required for homeokinesis, particularly in

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extreme sports. Yet the reason for this value of 37 °C is unclear, and the questions “why have mammals evolved to regulate stable body temperatures?” and “why are set points so much higher than environmental temperatures?” remain largely unanswered. The latter is an especially important consideration because in cold environments humans can lose body heat to the environment quickly. A stable body temperature is important to maintain optimum enzyme effectiveness by minimising temperature fluctuations [1], but the answer to the second question is still unclear despite the presentation of several biological theories attempting to explain the link. Humans might have a higher body temperature than the environment because of natural selection pressures that forced higher body temperatures as a result of metabolic heat production (physical activity, metabolism, growth, reproduction and digestion) and decreased heat conductance [2, 3]. Water temperature around 40 °C is associated with the least thermodynamic stress [4], and there is an exponential increase in water vapour via respiration above 40 °C [5]. Moreover, the speed of muscle shortening is faster at higher temperatures, and nerve conduction is faster [6], and this might have been an evolutionary benefit.

In a classic study, Mendelssohn [7] observed the behaviour of *Paramecia* (motile single-celled organism) in response to different environmental temperatures. When the extremities of a medium ranged from 12 to 36 °C, the *Paramecia* congregated around 25 °C temperature region and avoided cooler and warmer temperatures, suggesting that early organisms had a biological temperature preference. The close relationship between environmental and body temperature might explain why a set point of 37 °C is important; however, there is no clear evidence regarding the preference of environmental temperature and human evolution [8]. Despite this Gisolfi and Mora [9] propose that there is a close mathematical link between the apparent optimal environmental temperature of 25 °C and human body temperature based upon the Q^{10} temperature coefficient. A higher body temperature than environmental temperature might have been preferable to limit heat gain from the environment and allow sweat responses and reliance on body water to be regulated at thresholds that would not place the early human at risk of excessive water loss and dehydration.

31.3 Control of Body Temperature

Metabolic heat production can increase 3- to 12-fold above resting values (≈100 W) during physical exertion [10]. Skeletal muscle action is ≈20 % effective, and ≈80 % of energy is liberated as heat that must be dissipated from the body to avoid the consequences of excessive heat storage [11]. In an attempt to balance heat production and heat loss, cardiovascular adjustments are made to transport heat, generated in locomotor muscles, to the skin surface. Most extreme sports are associated with high metabolic heat production, and even in cold environments, athletes might require cooling. However, this often occurs quickly and might cause magnitudes of cooling beyond what is required – especially in cold water.

If a temperature gradient exists between the skin surface and its contacting medium, heat will be transferred by means of:

1. Conduction – heat transfer between two solid objects in direct contact
2. Convection – heat transfer between a surface (e.g. skin) and a fluid, such as air or water

In thermoneutral environments, standing whilst wearing shorts and shoes, heat exchange by conduction is minimal because the thermal gradient between the human and contacted surface (shoes/floor) is likely to be small. Heat exchange might increase if a fan or wind speed is increased because convective heat exchange is increased as warm air surrounding the skin surface is circulated and replaced with cooler air. The magnitude of this is increased when immersed in water because it is denser than air and has greater thermal conductivity. This is one reason why immersion in water cooler than body temperature can severely challenge thermal balance.

3. Radiation – electromagnetic heat transfer between two objects (usually large objects such as the ground surface (tarmac) but also the sun).
4. Evaporation – kinetic energy of water molecule motion (latent heat of evaporation) removes body heat when liquid water phase changes to water vapour.

The effectiveness of these methods is dependent upon the biophysical properties of the environment [11] such that the gradient between ambient and skin surface temperature, relative humidity, air speed and solar radiation combine to affect the loss or gain of body heat.

This can be conceptualised in the form of the heat balance equation:

$$S = M\left(\pm W\right) \pm \left(R + C\right) \pm K - E$$

where

S = rate of body heat storage
M = rate of metabolic energy (heat) production
W = external mechanical force production (concentric, eccentric, isometric in isolation or combination)
$R + \mathrm{C}$ = rate of radiant and convective energy exchanges
K = rate of conduction (important when in water)
E = evaporative losses

The sum of this equation represents heat gain if positive and heat loss if negative, such that body temperature increases when S is positive, decreases when S is negative and remains the same when S is zero [11].

31.3.1 Neurological and Thermoregulatory Responses to Cold Stress

To regulate body temperature within a narrow range, humans combine behavioural and autonomic physiological processes [11]. Behavioural modifications during sport in cold environments are limited by the intensity of exercise or task and addition of clothing layers, whilst autonomic physiological modifications include decreased skin blood flow via cutaneous vasoconstriction, catecholamine secretion and shivering and non-shivering thermogenesis [12]. Autonomic reflexes are proposed to be under the control of a central integrator, presumed to be the preoptic anterior hypothalamus (POAH). The POAH receives information relayed from afferent thermoreceptors in the skin [13, 14], core [10] and brain [15]. Most skin thermosensors are cold sensitive, and sensory information from the skin triggers cold defence mechanisms [16–19]. When ambient temperatures drop below ~26 °C, cold-sensitive thermoreceptors [20] are activated and send projections via polysynaptic pathways to the POAH. The level of activation is referenced to an activation (temperature) 'set point', and when body temperature breaches a threshold from the 'set point', synaptic activation of cold-sensitive neurons is proposed to trigger autonomic heat gain reflexes.

The initial response to cold stress is a decrease in peripheral blood flow, primarily to the skin vasculature but also some peripheral regions of skeletal muscle. The response reduces heat loss via convection from the body core to the shell enabling the skin and subcutaneous fat to act as an insulative layer. As heat is lost from the skin surface but not replaced by blood flow, it is manifested as a decline in skin temperature. Vasoconstriction occurs when skin temperature drops below thermoneutral (34 °C) as cold-sensitive thermoreceptors in the skin are rapidly activated. Maximal vasoconstriction is environment specific and occurs at a higher skin temperature (31 °C) in whole-body water immersion and lower (26–28 °C) during local cooling. Thus, the initial vasoconstrictive response is an effective cold defence mechanism but is at the detriment to blood pressure regulation, skin temperature and in particular muscle temperature.

Typical intramuscular temperature under thermoneutral conditions is around 35 °C, and within the region of 27–35 °C, there appears to be no substantial effects on muscular force production [6]. However, at temperatures of 20 °C and below, muscle force is substantially impaired. Several methodological issues limit the direct comparison of research on muscle cooling and force production [21], but the general consensus is that muscle force production is not substantially impaired until muscle temperature drops below 27 °C [21, 22]. It is worth noting that most of the studies investigating muscle temperature have used local passive cooling designs and as such the results might not extend to whole-body cooling during exercise as often occurs in extreme environments. Nevertheless cold muscles impair force production and performance and increase the risk of hypothermia. It is likely that the reduced ability to produce force is due to a combination of reduced metabolic rate [21], impaired kinetics of muscle fibre action potentials, reduced actomyosin ATPase activity and calcium release from the sarcoplasmic reticulum, thus restricting cross-bridge cycling [21]. Reduced force production and muscular co-ordination is of particular concern in extreme sports. A reduction in dexterity during sports such as climbing can impair performance and increase risk of injury, whilst individuals who compete in water sports or in arctic competitions might find it difficult to perform fine motor skills. Moreover in life-threatening situations impaired dexterity can increase time to take control measures such as opening kit bags, layering on more clothes, using first-aid equipment and operating technical equipment (e.g. radios). In situations that cause rapid reductions in muscle temperature but full consciousness/awareness such as whole-body cold water immersion, decisions to perform activity (such as swimming to safety) might accelerate exhaustion due to ineffective muscle activity prior to reaching critical hypothermia – in these instances exhaustion can cause drowning and might be the primary risk to survival.

31.3.2 Thermoregulatory Responses to Cold Stress

The physiological challenges induced by reductions in core temperature are listed in Table 31.1. Humans generally tolerate reductions in body temperature around 2 °C before maximal shivering occurs. Thereafter, reductions in body temperature continue despite shivering and might cause amnesia and

Table. 31.1 Typical physiological responses to decreases in core temperature

Stage	Core temperature (°C)	Physiological response
Normothermia	37	
Mild hypothermia	35	Maximal shivering
		Increased blood pressure
	34	Amnesia
		Dysarthria
		Poor judgement
		Behaviour change
	33	Ataxia
		Apathy
Moderate hypothermia	32	Stupor
	31	Shivering ceases
		Pupils dilate
	30	Cardiac arrhythmias
		Decreased cardiac output
	29	Unconsciousness
Severe hypothermia	28	Ventricular fibrillation
		Likely hypoventilation
	27	Loss of reflexes and voluntary motion
	26	Acid-base disturbances
		No response to pain
	25	Reduced cerebral blood flow
	24	Hypotension
		Bradycardia
		Pulmonary edema
	23	No corneal reflexes
		Areflexia
	19	Electroencephalographic silence
	18	Asystole
	15.2	Lowest infant survival from accidental hypothermia
	13.7	Lowest adult survival from accidental hypothermia

Adapted from Castellani et al. [23]

poor judgement (such as not taking shelter) before cardiac arrhythmias and unconsciousness occur around 30 °C.

31.4 Predisposing Factors for Cold Strain

Physiological responses to cold exposure might vary between individuals because of sex differences, anthropometrics, fitness and level of acclimatisation to the particular environmental condition. For example, individuals who have a large body surface area, are lean and have a small body mass (ectomorphic) tend to lose body heat content quickly in low ambient or water temperatures when metabolic heat production is low [24, 25]. This is because there is a large skin surface area for convective heat exchange to occur. The opposite is true for endomorphs; the added thermal resistance of adipose tissue lends well to heat conservation [26], and there is evidence to suggest that individuals with body fat percentages greater than 25 % have a higher threshold for vasoconstriction enabling them to limit heat loss [27]. When compared to men of comparable age and body mass, generally women have more body fat content, greater subcutaneous fat content, less muscle mass, higher surface to mass ratio and are more resistant to cold stress. However, when matched for body fatness, there are little gender differences [28], and in most cases women have a greater surface area but smaller body mass and musculature than men placing them at a greater risk of rapid declines in body temperature. These anthropometric characteristics are similar to that of children who have less subcutaneous fat compared to adults thus tend to lose body heat content faster [25] despite more pronounced vasoconstrictor and metabolic responses compared to men [29]. Conversely, populations of advanced age (>60 years) exhibit impaired thermosensitivity, vasoconstriction and heat conservation [30–33] and because of a generally lower level of physical fitness produce less metabolic heat during activity that might lead to a more pronounced rate of heat loss when compared to young healthy counterparts. However, in younger adults physical fitness appears to have a minor influence on thermoregulatory responses to cold. Cutaneous vasoconstrictor activity might be upregulated after endurance training [34] but with little impact on maintenance of core temperature. Resistance-trained athletes might have higher metabolic heat production due to greater muscle mass, allowing them to produce more body heat in the cold [26]. The human adaptive response to repeated cold stress is likely individual specific and is modest compared to heat stress [35]. It is believed that three possible mechanisms might contribute to cold adaptation:

1. Blunted physiological responses to cold stress (habituation)
2. Enhanced thermogenic response (metabolic)
3. Enhanced body heat conservation (insulative)

Despite the belief that the cold-adapted individuals are able to produce more metabolic heat, evidence to suggest this is limited to case studies and weak observational experimental designs [35–39]. Nevertheless shivering is a response to cold stress that increases metabolic heat production, and it is possible that individuals that are adapted to the cold are able to generate more metabolic heat through shivering and non-shivering thermogenesis in comparison to unacclimated persons. Insulative adaptations might occur through enhanced regulation of cutaneous blood flow. Convective heat losses are likely to be minimised as the cold-acclimated individual constricts peripheral blood vessels, reducing blood flow and narrowing the gradient between skin temperature and the environment [40]. Conversely these adaptive physiological responses might be blunted by habituation, particularly metabolic heat production [41, 42]. However, blunted shivering and metabolic heat production limit heat loss and are aided by cutaneous vasoconstriction [40]. In most circumstances, adaptations are environmental and context specific, and behavioural adjustments such as seeking warmth and layering clothing become the primary method of defence against hypothermia. In recent years technological advancements, such as

Table 31.2 Factors that might challenge human thermoregulation in cold environments

Increased heat loss	Impaired thermoregulation	Miscellaneous clinical states
Training factors	*Peripheral failure*	Infection Renal failure
Immersion Rain Wet clothing Wind	Trauma Neuropathies Acute spinal cord transection	
Erythrodermas	*Central failure*	
Burns Psoriasis Ichthyosis Exfoliate dermatitis Sunburn	Central nervous system lesions and trauma Stroke Subarachnoid haemorrhage Hypothalamic dysfunction Parkinson's disease Multiple sclerosis Pharmacologic Toxicological Drug and alcohol abuse	
Iatrogenic		
Emergency birth Cold infusions Heat illness Open wound		

Adapted from Castellani et al. [23]

the development of wetsuits for diving in cold water and insulative and wind-protective clothing, have advanced human ability to function and survive cold environments. It should be noted that despite these general concepts, even those matched for anthropometrics, sex, age and acclimatisation and when combined with training factors such as inactivity, fatigue, lack of sleep and endocrine (hypopituitarism, hypoadrenalism, hypothyroidism, hypoglycaemia, diabetes), individual responses to cold stress can vary widely [23].

Clearly the physiological responses to cold stress are highly specific to an individual and the context of the situation. Table 31.2 summarises different environmental and medical factors that might challenge thermoregulation in cold environments (Table. 31.2). Athletes competing in extreme sports events in extreme weather conditions are at most risk due to environment; sadly however, there are circumstances in extreme sports that increase the risk of medical events, and these also play an important role in the magnitude of cold strain, thermoregulatory strain and the treatment hypothermia.

31.5 Risk Management Strategies

It is beyond the scope of this chapter to offer medical guidance regarding the treatment of cold injuries, but the prevention of mild hypothermia (defined as a core temperature 35 °C) is in the interest of all parties involved in extreme sports. Strategies designed to reduce the risk cold injuries have been presented in detail [23, 26] and will be summarised here in relation to the context of this chapter.

Figure 31.1 depicts risk management procedures for evaluating cold stress and strain thus preventing hypothermia (Fig. 31.1). It should be noted from the onset that the risk of hypothermia can decrease substantially when coaches, athletes and scientists are aware of the risks:

- Specific combination of the sport, environment and individual
- Understanding of the key monitoring procedures and derived data
- Awareness of the acute treatment of mild hypothermia

Identifying potential hazards and preparing for changes in risk factors are crucial for the

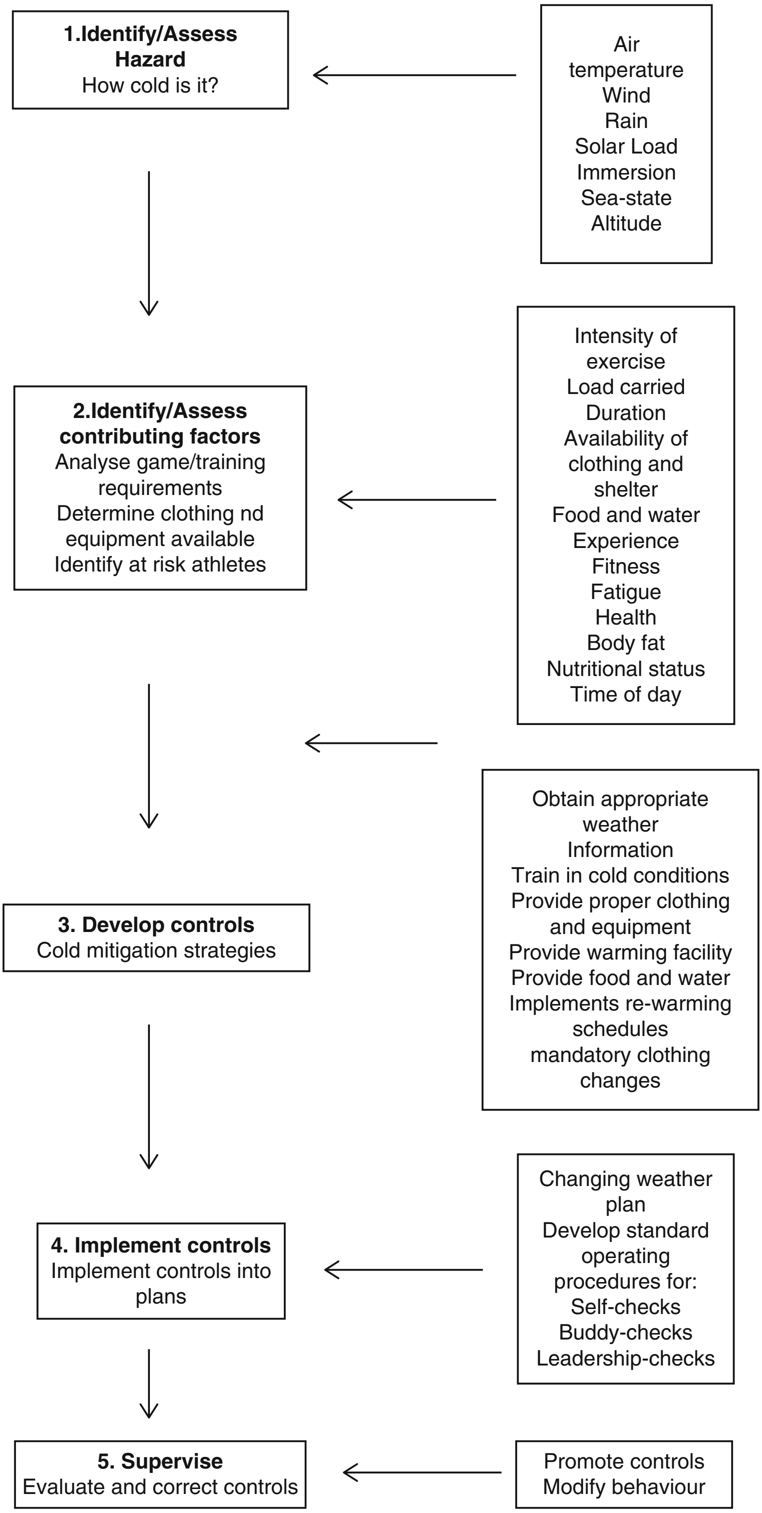

Fig. 31.1 Risk management strategies (Adapted from Golden and Tipton [42])

successful prevention of hypothermia. As cold strain is primarily determined by the environment, real-time weather reports and valid forecasting for the time of day are essential inputs to the model. For sports that compete in water, valid historical and real-time monitoring of temperature is also important. Factors that can substantially increase the risk of cold injuries in low ambient temperature are wind, rain and altitude; it should be noted that water immersion even at 20 °C can substantially increase the risk of hypothermia, even when active. Therefore, it is important that the sport and individual are assessed in combination with the environment. Factors that influence mean metabolic heat production such as the intensity and duration of exercise, work to rest ratios and body composition influence risk management strategies. If performance is prolonged, then the fitness, nutritional status and magnitude of fatigue will combine to influence metabolic heat production. Typically when athletes are fatigued they are less able to exercise at an intensity that is sufficient to produce metabolic heat required to equilibrate the heat balance equation. Athletes are then at risk of losing body heat rapidly, usually through convective or evaporative mechanisms. Circumstances that are likely to deplete or challenge muscle glycogen stores should also be considered as hypoglycaemia impairs shivering response [43]. A complete understanding of the clothing an athlete will be wearing and its protective ability should also be established; in general the insulative properties of clothing should increase with the severity of the environmental conditions and potential for heat loss. The use of heat loss prediction models might be a useful starting point to assess the likelihood of hypothermia. It has been reported that even in seemingly compensable environments such as 10 km open water swimming at a temperature of 16 °C and speed of $1.4\ \mathrm{m \cdot s^{-1}}$, core temperature is predicted to fall to 35.7 °C, this might be greater considering when fatigue and a consequent decrease in metabolic heat production [26] manifest towards the end of the race. It is conceivable that slower swimmers or individuals with low cardiorespiratory fitness will be unable to sustain a sufficient intensity to maintain a safe body temperature. In consideration it is worth noting that the swimming distance permitted in open water swimming by British Triathlon decreases from 2000 m at 13 °C to 500 m at 11 °C. In water temperatures below 11 °C, it is recommended that swimming does not take place – these guidelines do not take into account wind speed an important component determining convective cooling, as such additional consideration should be given to the whole environment not just water temperature alone. Given that most extreme sports take place outdoors, individuals who are likely to be exposed to challenging conditions should be aware of availability of shelter. This is particularly important in events that take place over long distances in remote environments.

Approaches to identify potential risk factors should be accompanied by a rating of likelihood and the associated consequences. This evaluation assists in the development of flexible, rapidly implemented and responsive control strategies. Most controls are directly related to the risks such as close monitoring of environmental temperature but might include preparatory techniques for individuals at risk such as cold acclimation training, appropriate fuelling strategies, sufficient clothing and shelter at appropriate locations with adequate communication to event directors, accessible routes and flexible and responsive transport. The challenge to the risk management process is not in identifying and developing controls but an “across-the-board” implementation of strategies. Individuals who are responsible for participants competing in extreme sports such as officials, coaches, medical doctors, other athletes and the competing individual should be fully aware of the risks, monitoring procedures and acute first-response strategies. An increased awareness is context specific but might include specific training sessions, an outline of the strategies in pre-competition information packs and strategically placed information around the site/venue on competition day.

Conclusion

The challenges faced by competition in cold environments are not restricted to the athlete but the event as a whole. A large and physiologically demanding integrative response is required to maintain thermal equilibrium and drive homeokinesis in extremely cold environments; the reasons for these responses are clear, but the origins of our homeostatic set point are not so. When body temperature decreases, it becomes difficult to co-ordinate and produce muscular force. These principal factors place not just performance but often survival at risk. The available research indicates that young and elderly persons are more at risk of cold injury with the risks exacerbated by low activity (heat production) as a consequence of low or impaired cardiovascular fitness. However, anthropometrics and morphology alone cannot fully explain the consequences of cold stress as it is highly individual and context specific. With this in mind risk management strategies should be employed to identify the likelihood of cold injury for a range of situations and environmental conditions. Sports that take place in cold and wet environments should carefully consider the safety of athletes, officials and spectators and have well-drilled, adaptive and responsive systems that are able to integrate a range of factors to make decisive decisions.

References

1. Heinrich B. Why have some animals evolved to regulate high body temperatures? Am Nat. 1977;111: 623–40.
2. McNab BK. The metabolism of Fossorial Rodents: a study of convergence. Ecology. 1966;47:712–33.
3. Hamilton WJI. Life's color code. New York: McGraw-Hill; 1973.
4. Calloway NO. Body temperature: thermodynamics of homeothermism. J Theor Biol. 1976;57(2):331–44.
5. McGowan C. Selection pressure for high body temperature: implications for dinosaurs. Paleobiology. 1977;5(3):285–95.
6. Ranatunga KW. The force-velocity relation of rat fast-and slow-twitch muscles examined at different temperatures. J Physiol. 1984;351:517–29.
7. Mendelssohn M. Uber den thermotropismus einzelliger organismen. Pflugers Arch. 1895;60:1–27.
8. Marino FE. The evolutionary basis of thermoregulation and exercise performance. In: Marino FE, editor. Thermoregulation and human performance. Physiological and biological aspects. Basel: Karger; 2008. p. 1–13.
9. Gisolfi CV, Mora F. The hot brain: survival, temperature and the human body. Cambridge: MIT Press; 2000.
10. Gleeson M. Temperature regulation during exercise. Int J Sports Med. 1998;19(2):96–9.
11. Sawka MN, Leon LR, Montain SJ, Sonna LA. Integrated physiological mechanisms of exercise performance, adaptation, and maladaptation to heat stress. Compr Physiol. 2011;1(4):1883–928.
12. Stocks JM, Taylor NA, Tipton MJ, Greenleaf JE. Human physiological responses to cold exposure. Aviat Space Environ Med. 2004;75(5):444–57.
13. Nadel ER, Bullard RW, Stolwijk JA. Importance of skin temperature in the regulation of sweating. J Appl Physiol. 1971;31(1):80–7.
14. Hensel H. Thermoreception and temperature regulation. New York: Academic Press; 1981.
15. Nybo L, Secher NH, Nielsen B. Inadequate heat release from the human brain during prolonged exercise with hyperthermia. J Physiol. 2002;545(2): 697–704.
16. Sakurada S, Shido O, Fujikake K, Nagasaka T. Relationship between body core and peripheral temperatures at the onset of thermoregulatory responses in rats. Jpn J Physiol. 1993;43(5):659–67.
17. Bratincsak A, Palkovits M. Evidence that peripheral rather than intracranial thermal signals induce thermoregulation. Neuroscience. 2005;135(2):525–32.
18. Tanaka M, Owens NC, Nagashima K, Kanosue K, McAllen RM. Reflex activation of rat fusimotor neurons by body surface cooling, and its dependence on the medullary raphe. J Physiol. 2006;572(2):569–83.
19. Nakamura K, Morrison SF. A thermosensory pathway mediating heat-defense responses. Proc Natl Acad Sci U S A. 2010;107(19):8848–53.
20. Bautista DM, Siemens J, Glazer JM, Tsuruda PR, Basbaum AI, Stucky CL, Jordt SE, Julius D. The menthol receptor TRPM8 is the principal detector of environmental cold. Nature. 2007;448(7150):204–8.
21. Drinkwater E. Effect of peripheral cooling on characteristics of local muscle. In Marino FE, editor. Thermoregulation and human performance. Physiological and biological aspects. Basel: Karger; 2008. p. 74–88.
22. De Ruiter CJ, De Haan A. Temperature effect on the force/velocity relationship of the fresh and fatigued human adductor pollicis muscle. Pflugers Archiv Eur J Physiol. 2000;440(1):163–70.
23. Castellani JW, Young AJ, Ducharme MB, Giesbrecht GG, Glickman E, Sallis RE, American College of Sports Medicine. American College of Sports Medicine position stand: prevention of cold injuries during exercise. Med Sci Sports Exerc. 2006; 38(11):2012–29.
24. Elsworth R, Buskirk RH, Thompson G, Whedon D. Metabolic response to cold air in men and women in relation to total body fat content. J Appl Physiol. 1963;18:603–12.

25. Sloan RE, Keatinge WR. Cooling rates of young people swimming in cold water. J Appl Physiol. 1973;35(3):371–5.
26. Castellani JW, Young AJ. Health and performance challenges during sports training and competition in cold weather. Br J Sports Med. 2012;46(11):788–91.
27. Kasai T, Hirose M, Matsukawa T, Takamata A, Tanaka Y. The vasoconstriction threshold is increased in obese patients during general anaesthesia. Acta Anaesthesiol Scand. 2003;47(5):588–92.
28. Tikuisis P, Jacobs I, Moroz D, Vallerand AL, Martineau L. Comparison of thermoregulatory responses between men and women immersed in cold water. J Appl Physiol (Bethesda: 1985). 2000;89(4):1403–11.
29. Smolander J, Bar Or O, Korhonen O, Ilmarinen J. Thermoregulation during rest and exercise in the cold in pre- and early pubescent boys and in young men. J Appl Physiol (Bethesda; 1985). 1992;72(4):1589–94.
30. Kenney WL, Armstrong CG. Reflex peripheral vasoconstriction is diminished in older men. J Appl Physiol (Bethesda; 1985). 1996;80(2):512–5.
31. Smolander J. Effect of cold exposure on older humans. Int J Sports Med. 2002;23(2):86–92.
32. Young AJ, Lee DT. Aging and human cold tolerance. Exp Aging Res. 1997;23(1):45–67.
33. Ohnaka T, Tochihara Y, Tsuzuki K, Nagai Y, Tokuda T, Kawashima Y. Preferred temperature of the elderly after cold and heat exposures determined by individual self-selection of air temperature. J Therm Biol. 1993;18(5–6):349–53.
34. Savourey G, Bittel J. Thermoregulatory changes in the cold induced by physical training in humans. Eur J Appl Physiol Occup Physiol. 1998;78(5):379–84.
35. Sawka MN, Castellani JW, Pandalf KB, Young AJ. Human adaptations to heat and cold stress; 2002. http://ftp.rta.nato.int/public/PubFullText/RTO/MP/RTO-MP-076/MP-076-$KN4.pdf. Accessed Oct 2014.
36. Hammel HT. Thermal and metabolic responses of the Alacaluf Indians to moderate cold exposure. WADC technical report. United States. Air Force. Wright Air Development Center, Dayton, 1960;60–633:1–44.
37. Junghans P, Schrader G, Faust H, Wagner B, Hirschberg K, Reinhardt R. Studies of the protein and the energy metabolism in man during a wintering in Antarctica. Isotopes Environ Health Stud. 2012;48(2):208–25.
38. Snodgrass JJ, Leonard WR, Tarskaia LA, Alekseev VP, Krivoshapkin VG. Basal metabolic rate in the Yakut (Sakha) of Siberia. Am J Hum Biol (The Official Journal of the Human Biology Council). 2005;17(2):155–72.
39. Van Ooijen AM, Van Marken Lichtenbelt WD, Van Steenhoven AA, Westerterp KR. Seasonal changes in metabolic and temperature responses to cold air in humans. Physiol Behav. 2004;82(2-3):545–53.
40. Wakabayashi H, Wijayanto T, Kuroki H, Lee JY, Tochihara Y. The effect of repeated mild cold water immersions on the adaptation of the vasomotor responses. Int J Biometeorol. 2012;56(4):631–7.
41. Budd GM, Brotherhood JR, Beasley FA, Hendrie AL, Jeffery SE, Lincoln GJ, Solaga AT. Effects of acclimatization to cold baths on men's responses to whole-body cooling in air. Eur J Appl Physiol Occup Physiol. 1993;67(5):438–49.
42. Golden FS, Tipton MJ. Human adaptation to repeated cold immersions. J Physiol. 1988;396:349–63.
43. Passias TC, Meneilly GS, Mekjavic IB. Effect of hypoglycemia on thermoregulatory responses. J Appl Physiol (Bethesda; 1985). 1996;80(3):1021–32.

Helmets: Technological Innovations for Safety

32

Andrew S. McIntosh and Declan A. Patton

32.1 Introduction

Well-designed helmets that are the correct size, properly fitted and fit for purpose are highly effective in preventing head injury, including skull and brain injury [1–3]. However, when one or more of these prerequisites are violated, helmets are less or not effective. This chapter will focus on the topic of fit for purpose in the context of extreme sports. Fit for purpose means that the helmet is functional for the activities in which it is worn and protects the head within a sport's injury risk management objectives. For example, if the objective is to prevent severe skull and brain injury in a high velocity impact, a helmet without any impact energy attenuating liner will not satisfy that objective. If, on the other hand, the objective is to provide protection against minor impacts that might disturb the wearer or cause superficial injury, a helmet comprising of a shell and comfort liner may suffice. Setting the risk management objectives is a critical step to ensure that the helmet matches the expectations of the athlete. If people elect to wear a helmet that is too large, or the restraint system is loose or not fastened, then they will not benefit fully from a helmet.

32.2 The Injury Risk Management Objective

As individuals and collective, we need to consider injury risks in sports and then determine our objectives in terms of controlling such risks. Injury risk can be expressed as the product of injury likelihood and consequences. Individuals can practise and train for extreme sports, so that they have the skills to meet the challenges of the sport. Individuals can make informed decisions about risks at specific times, e.g. the weather, and the preparation of their equipment. It is not expected that an individual will manufacture a helmet. Therefore, the sport collectively needs, as part of its risk management objectives and strategic planning, to make decisions about the scope and objectives regarding helmet function. This creates the right operational environment for helmet suppliers, standards organisations, certification bodies and conformity assessment bodies (CAB). Ultimately, this means that there is confidence that the helmet worn by the athlete is fit for purpose and complies with the sport's regulations. The risk management process within the sport establishes the safety and business cases for new

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equipment, revising standards, developing helmet tests methods or mandating equipment [3, 4].

Many sports do not know what the injury risks are in the sport. There is often only anecdotal evidence and collective knowledge arising from catastrophic events, deaths, personal experience and folk law. This book will go some way in providing a snap shot of knowledge around injury risks in extreme sports. It is fair to say that in all extreme sports there is a risk of head injury, often a risk of catastrophic or fatal head injury. The risk exists because the sports by their nature involve high kinetic or potential energy and the individual is not contained in a crashworthy vehicle. Whether a helmet can mitigate those risks is questionable. A system-based approach to safety is required in which a helmet is only one component.

Decisions around risk management objectives are tightly coupled with helmet standards. Hypothetically, if a helmet was required to cushion a gentle tap on the head, the impact assessed in the standard would also be gentle. In contrast, if a helmet is intended to reduce head injury severity in a fall from a height, e.g. 5 m, the impacts assessed in the standard might also include tests from 5 m (9.9 m/s or 36 km/h impact speed). Participants and representative bodies in extreme sports might consider that there is a range of hazards (e.g. falls) that are unsurvivable; even if the head was protected, the athlete would die from severe thoracic or spinal injuries. Evidence-based and considered decisions might focus on helmets that will offer protection in incidents that are potentially survivable. These are issues for the sport to consider collectively in the context of national and international legal and ethical frameworks.

32.3 Helmet Design and Function

A typical helmet comprises the following components: shell, impact attenuating liner, comfort/sizing pads and restraint system [3, 5, 6]. Some helmets have no shell or the shell is moulded into the liner, e.g. modern bicycle helmets. Some helmets have no impact attenuating liner. Helmet standards are typically performance based; therefore, within reason, as long as a helmet satisfies the performance tests, they will meet the standard regardless of the actual construction. Shells are constructed from a range of materials, e.g. ABS plastic, fibreglass or carbon fibre. Liners are also constructed from a range of polymeric foams, e.g. expanded polystyrene (EPS), expanded polypropylene (EPP) and polyurethane (PU). Excluding ballistics helmets, helmets offer limited protection unless they have a substantial liner. Many liners seem incompressible, but under the target impact conditions, they deform, which reduces the forces acting on the head. Liners that are soft and easily compressed provide comfort and sizing options but do little to protect the head.

There are two basic principles at play in the design and performance of helmets: conservation of energy and load distribution.

32.3.1 Conservation of Energy

Most extreme sports involve athletes gaining potential energy, e.g. becoming elevated, and converting that potential energy into kinetic energy as they dive, ski, jump or cycle down a mountain. In others, wind or powered craft accelerate the athlete to a velocity. What is relevant is the athlete's velocity. The head can be considered to be a rigid body. Its mass is approximately 5 kg, for the sake of simplicity. Kinetic energy (KE) is mass (m) by velocity (v) squared divided by 2:

$$\mathrm{KE} = ½ m v^2$$

A 5 kg head travelling at 9.9 m/s has a kinetic energy of 245 J. Dropping the 5 kg head 5 m will result in the head having 245 J on impact. On impact, work is performed on the head to stop it. If we consider conservation of energy and just potential energy (PE), kinetic energy and work (W), we arrive at the following relationship:

$$\mathrm{PE}_i + \mathrm{KE}_i + W = \mathrm{PE}_f + \mathrm{KE}_f$$

where 'i' and 'f' are two moments in time, e.g. just before impact ('i' for initial) and at the end of an impact ('f' for final). If we consider that time period, PE can be ignored, and with the object stopping, there is no KE_f. Work equals force (F) by displacement (s). Therefore, simplistically:

$$KE_i = W \text{ or } ½mv^2 = Fs \text{ or } F = \left(½mv^2\right)/s$$

As can be seen the impact force is sensitive to the velocity, which is squared, and the displacement. With greater displacement, the force is reduced.

If the helmet brought the 245 J impacting head to a full stop in 30 mm, the average force during the impact would be approximately 8200 N. However, typically, the peak force is significantly greater than the average. A liner would need to be considerably thicker than 30 mm to deform during the impact by 30 mm. This simple and hypothetical example presents the challenge in developing a helmet. An impact force of at least 8200 N will result in considerable head injury. If the helmet liner was 45 mm with a 5 mm shell, then the minimum thickness of the helmet will be 50 mm. If a more effective helmet is desired, greater liner deformation is required, which means a larger and thicker helmet.

One topic not considered above is the stiffness and viscoelasticity of the liner. The material needs to be able to deform 30 mm in this impact. A very rigid material will not deform and a very soft material will fully deform, both doing very little to attenuate the impact. In both of these extreme cases, the head will be brought to a sudden stop in much less than 30 mm.

As foreshadowed in the introduction, the test conditions need to reflect relevant injury risk management objectives, so that the test method will be suitable and the materials and design of the helmet appropriate [3]. Test methods will be considered later in the chapter.

32.3.2 Load Distribution

Helmets can provide a load distributing function so that the pressure placed on the head is reduced. For example, if the head collides with a rock, a small area of the head is initially loaded. That area progressively gets larger and engages more of the surface area of the head. If there is sufficient force in this situation, local brain contusion will occur and the skull will deform and fracture. The impact will also cause a laceration of the scalp. A shell can reduce the local pressure and deformation. A shell can distribute the impact force over a larger surface area of the head and reduce the risk of head injury.

Some helmets are also assessed for their ability to resist a penetrating load and their integrity under such a load.

Great success has been achieved by helmets to reduce severe head injury through impact acceleration management and load distribution. Attention has turned to other mechanisms of brain injury, such as angular acceleration, and how helmets might be improved to reduce angular acceleration further [3, 6].

32.3.3 Restraint Systems

The restraint system is also critical as it retains the helmet on the head and in a position and orientation that provides protection. Ideally, a helmet should stay in place under all circumstances; however, in extreme sports there may be situations in which helmets could give rise to tensile forces that could injure the cervical spine. Aerodynamic and hydrodynamic forces, e.g. ‘bucketing’, might lead to a situation in which the forces are pulling the helmet away from the head and through the restraint system causing tensile forces on the cervical spine. This could lead to asphyxia or cervical spine injury. For the typical helmet, e.g. bicycle or motorcycle, we consider the minimum strength requirement not the maximum. Research on bicycle and motorcycle helmets gives us confidence that this is an appropriate approach [1, 2]. Research does not show, for example, that bicycle helmets increase neck injury risks or strangulation risks. This does not mean that there are no cases in which this has occurred; however, it means that on a population level, this does not emerge as a risk. It might be necessary to consider restraint system strength requirement limits for some helmets used in extreme sports. Again, this is highly dependent on the risks in the sport and the risk management objectives. These are very challenging ethical issues. If helmet performance moved in this direction, then a test would require a helmet restraint system to be able to sustain a specific test load, e.g. 1000 N, without exceeding a specified elongation, e.g. 20 mm, but then fail at a specified higher test load, e.g. 1500 N. This could be engineered through selection of materials. For example, the selection of webbing will minimise elongation, and the plastic buckle could be designed to fail at a specific force.

32.4 Standards and Test Methods

32.4.1 Scope and Objectives

Certain aspects of helmet design and function are codified into a written document called a Standard or Technical Specification [3]. These documents contain normative (mandatory) and informative (guidance) requirements. The documents typically indentify the scope and objectives of the standard, e.g. *a helmet for skydiving that is intended to prevent concussion and superficial head injuries arising from impacts inside the plane, with other skydivers and in an uncontrolled low speed landing*. This describes what injuries the helmet is intended to prevent and the circumstances in which the helmet is intended to function. This statement needs to be consistent with the test specifications. An alternative might be for a helmet for competitive alpine skiing and snowboarding, e.g. *a helmet for competitive alpine skiing and snowboarding that is intended to prevent serious head injuries arising from high speed impacts*. The test specifications for the two hypothetical helmets will be quite different. The most obvious difference is that the test impacts for the alpine helmet will be more severe, i.e. at a higher velocity, than the skydiving helmets. In addition, in the impact tests the expected performance will be different. It might be reasonable to establish these standards along the lines described above, from a practical perspective. Helmets can perform within the specifications described above for alpine sports and skydiving. However, it would not be possible within our current technology to have a skydiving helmet that protects the head from an impact at terminal velocity, e.g. 54 m/s.

A helmet standard or technical specification may include tests of: impact energy attenuation, load distribution, strength of retention system (dynamic or static), stability (dynamic or static), buoyancy and resistance to penetration. The standard can include an inspection protocol regarding internal and external projection dimensions, in addition to marking and labelling. Tests can be specified to be undertaken on helmets conditioned to hot, cold or wet. Additional tests can be specified for visors and other accessories. Three of these test methods will be described: impact energy attenuation, helmet stability and restraint system strength.

32.4.2 Impact Energy Attenuation

Impact energy attenuation tests involve dropping a headform upon which a helmet is placed onto an anvil from a height (Fig. 32.1). The height, or velocity, the headform and the anvil are defined. In some tests a projectile is fired at the helmet headform or an impact is applied using a special device [7]. A projectile impact is probably more relevant in a projectile sport than dropping the

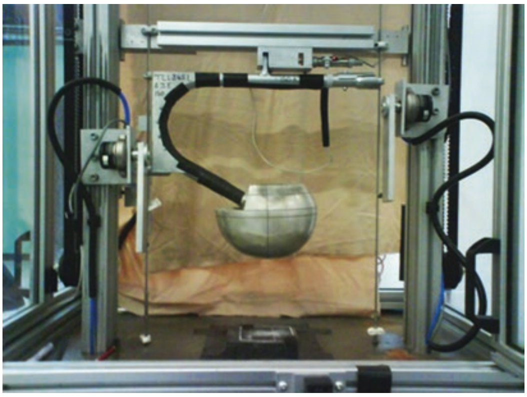

Fig. 32.1 Drop assembly for guided two wire drop test. The headform is shaped like a human cranium and can be rotated to orient the impact to selected sites on the helmet. The helmet is placed over the headform. In this specific test configuration, a single accelerometer is mounted inside the head, and it is always oriented along a vertical axis, regardless of the orientation of the headform

Table 32.1 Comparison of impact energy requirements in standards for snow sports helmets

Standard	Drop height (m)	Peak headform accel. (g)	Anvil	Drop height (m)	Peak headform accel. (g)	Anvil	Drop height (m)	Peak headform accel. (g)	Anvil
Snell RS-98[a]	2.0	<300	Flat	1.6	<300	Hemi	1.6	<300	Edge
EN 1077: 2007	1.5	<250	Flat	–	–	–	–	–	–
ASTM F2040 - 06	2.0	<300	Flat	1.2	<300	Hemi	1.0	<300	Edge
FIS rule 6.2.1 Sept. 2013[b]	2.4	<250	Flat						

Note:

[a] The Snell RS-98 drop heights are based on a 5 kg drop assembly

[b] FIS rule for GS/SG/DH and requires helmet to be certified to ASTM 2040 and EN 1077

helmet onto an anvil. More recently, methods have been developed with which to subject helmets to oblique impacts, where there are two impact velocity components [8, 9].

Table 32.1 presents the differences between three standards and the 2013 International Ski Federation (FIS) rule for helmets in downhill (DH), super G (SG) and giant slalom (GS) competitions.

Helmets worn in International Ski Federation (FIS) competition in 2010 were required to conform to a snow sports helmet standard such as EN 1077 or ASTM F2040, SNELL or RS 98 [3]. As of 2013, helmets intended for DH, SG and GS must meet ASTM 2040 and EN 1077, as well as impact tests at a speed of 6.8 m/s. A similar ‘high performance’ approach was taken by the Australian horse racing sector in 2012 with regulation ARB HS 2012, in which compliance to one of three national standards is required in addition to performance in a set of more severe impact tests.

The critical issues are: energy, anvil, pass criterion and delivery mechanism.

As described above, the energy needs to reflect a typical hazard consistent with the sport’s risk management objectives. Many bicycle helmet tests require a drop test from 1.5 m. Research has shown that this reflects a typical range of impacts; however, it might not be consistent with mountain biking hazards [3]. Those hazards might be equated to a more severe impact arising from a fall from a height or the head colliding with a tree or stone with an impact speed close to that of the travel speed, e.g. 50 km/h, which is the speed an object reaches after being dropped from a height of 9.8 m.

Various anvils are used (Table 32.1), which are intended to address specific hazards. A flat anvil is normally used for bicycle helmet tests because the majority of the real-world impacts are against flat surfaces. In comparison a mountain biking helmet might be assessed against an edge and/or hemispherical anvil. The anvils are rigid because this provides repeatability for the tests.

Apart from snow sports, there are few extreme sports that currently have helmet standards. Helmets used in airborne sports, e.g. hang-gliding and paragliding, adhere to EN 966, which requires drop testing from 1.5 m onto both flat and kerb anvils under high temperature, low temperature and UV ageing conditions. Some helmets used in partially airborne sports adhere to EN 966, and another relevant standard, e.g. snowkiting helmets, may meet standards for both airborne sports and snow sports. In 2003, the Snell Foundation drafted a standard for extreme sports helmets (NX2003), the aim of which was to reduce head injuries in nonmotorised vehicle sports, e.g. skateboarding and roller blading. The Snell NX 2003 adhered to all the requirements of the Snell B-90 and CPSC bicycle helmet standards with two additional requirements. The standard requires that a helmet must manage impact sites 20 mm lower on the back of the head than the bicycle helmet standards. The standard also requires increased ‘shell toughness’ around the circumference of the helmet to manage tests at brow, sides and rear locations against a hazard anvil. As this extreme sports helmet standard never progressed beyond the draft stage, no helmet has been certified to this standard.

To date, pass criteria for these tests are linear headform acceleration related values, e.g. peak acceleration. To measure acceleration, a single linear accelerometer is placed in a guided drop assembly, or a triaxial accelerometer is used and the resultant derived. More recently, experimental work has focussed on developing angular acceleration and velocity-related criteria for oblique helmet impact tests. Many pass criteria are set in the range of 250–300 g (where 1 g is the acceleration due to gravity or 9.81 m/s^2). Mertz et al. [10] suggested that the 5 % likelihood value for skull fracture is 180 g for a midsized adult male [10]. The 50 % likelihood value for concussion is approximately 60 g for adult males [11]. Therefore, a helmet test with a rigid headform designed to satisfy a requirement to prevent 95 % of skull fractures, e.g. 200 g, is unlikely to prevent concussion. However, these values do not translate directly to a helmet test, because the headform properties differ from those of the human head. Typically, an impact measured on a human head will result in lower accelerations than the same impact with a rigid test headform. This discrepancy arises because of the deformability of the human head.

The energy delivery mechanism for helmet tests needs to be repeatable and reliable. The test needs to be quick and easy to execute, otherwise routine tests become expensive. Helmets are attached to a headform, raised and dropped onto an anvil with two or three wires guiding the free fall (Fig. 32.1). In some tests the helmet is mounted on an instrumented headform and projectiles are fired at the helmet. The energy is related to the projectile velocity and mass. There are other methods, e.g. linear impactors, for delivering the energy to the head.

32.4.3 Helmet Stability

In stability tests, the helmet is attached to a headform, the restraint system adjusted and then a static or dynamic load applied, which is intended to perturb the helmet and cause it to rotate. Figure 32.2 shows a test method for dynamic stability (Fig. 32.2). The helmet can be hooked at the front or rear and the dynamic load applied so

Fig. 32.2 Dynamic test of retention stability. In this test a motorcycle helmet is been assessed for the propensity of the helmet to roll forward on the headform. A hook is placed under the rear of the helmet. The hook is attached via a cable to a drop system that applies a dynamic load to the helmet

as to rotate the helmet forward over the face or rearward exposing the forehead. The dynamic load is applied by dropping a mass on a guide rod. When the mass hits the bottom plate, this 'jerks' the cable attached to the helmet.

32.4.4 Helmet Retention System Strength

Retention system strength is assessed by applying a static load onto the restraint system or applying a static preload followed by a dynamic load. Figure 32.3 presents the dynamic test method. In these tests, the amount of elongation and slippage of the webbing system is measured, as is any failure of the restraint system (Fig. 32.3).

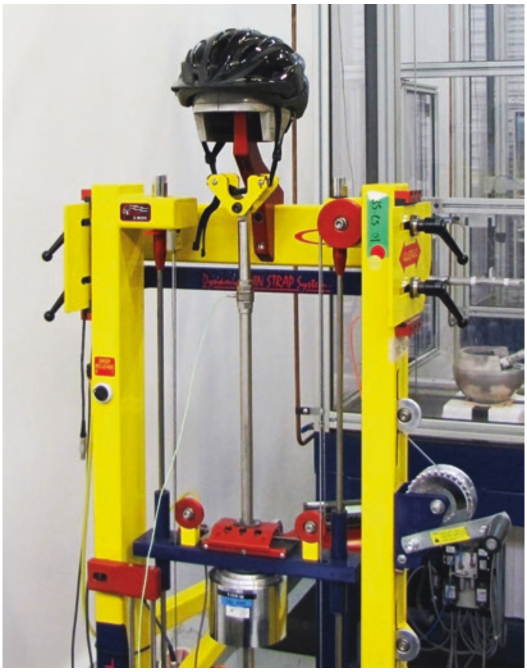

Fig. 32.3 Dynamic strength of retention system test rig. A bicycle helmet is being tested in this configuration. The restraint system is attached to a metal rod via a system of rollers (yellow 'V' section) that applies a static preload to the restraint system. A mass (silver steel cylinder towards bottom of image) is then dropped and impacts against a metal plate secured to the bottom of the rod. This applies a dynamic load to the restraint system. The displacement of the restraint system is measured and whether it has failed. In this specific configuration a force transducer has been added to measure the force on the restraint system

32.5 Helmet Design Limits

The design and production of a helmet requires balancing many specifications and requirements. The helmet needs to be wearable, i.e. comfortable and lightweight; it needs to comply with standards and must be affordable. As presented earlier, physics shows that increasing the stopping distance will decrease the impact force and improve helmet performance. On the other hand, increasing helmet thickness renders the helmet less acceptable and, in some circumstances, may make the helmet unwearable. A skydiver or motorcycle rider, for example, needs a helmet that does not induce intolerable aerodynamic forces onto the head and neck [12]. A mountain climber needs a helmet that does not impede mobility because it is too wide. The thickness requirement of the helmet needs to be established, after which the liner and shell material properties (type and density) need to be selected carefully to reach a final design. This is a very challenging design exercise, which is made even more so when the helmets are intended for extreme sports [4–6].

At present and as a general guide only, in terms of readily available and affordable consumer products, a well-designed and well-constructed bicycle or motorcycle helmet may offer protection to the head in an impact equivalent to a drop height of approximately 2.5 m [12–14]. Not all helmets provide this level of protection, and some may offer even greater protection, in particular motorcycle helmets. However, we can only be confident that the helmet complies with the standard unless presented with additional test data. If a sport wanted to be sure that the helmet offered protection in a 2.5 m impact tests, the sport would need to have a technical specification or standard reflecting this need. A drop of 2.5 m is equivalent to the head landing with a velocity vector of 7 m/s (25 km/h) directed towards the centre of mass of the head. In a real-world impact, there may also be a tangential impact velocity component that would make the resultant head impact velocity greater than 7 m/s. Therefore, this statement should not be taken to mean that a helmet will only protect someone riding a motorcycle or bicycle at a speed up to 25 km/h. More sophisticated 'oblique' helmet tests, which involve two impact velocity components, demonstrate that helmets perform in relevant real-world impact conditions that simulate the precrash travel speed in addition to the fall [3, 8, 9].

Motorcycle helmets offering this level of protection have a typical mass of 1.5 kg but can have a mass as high as 2 kg. Bicycle helmets have a mass that is typically less than 0.5 kg and often close to 0.3 kg. One of the reasons for the mass differences between these two types of helmets is the requirement for a substantial shell in a motorcycle helmet [12, 13].

The oblique helmet impact tests also show that current helmets reduce angular head kinematics, e.g. angular acceleration and velocity, which are considered to cause specific brain injuries, e.g. diffuse axonal injury and subdural haemorrhages. New technologies are being developed that may offer greater benefits in this area, e.g. MIPS®, which are intended to reduce angular head kinematics and related injury in impacts.

➜ *Putting this into the perspective of many extreme sports, helmets can be currently produced that are affordable, wearable, lightweight and offer protection in a limited range of impacts, e.g. up to 7 m/s, against a range of impact surfaces (flat, hemispherical or edge).*

32.6 Extreme Sports Helmets

Considering the sports listed in Table 32.2, and in consideration for current helmet performance, there are opportunities to supply climbing, snow, wheeled and water extreme sports with helmets that will offer protection to the head. There is a greater challenge in protecting the head with sports in the air, e.g. wingsuit flying. As described earlier in the chapter, each sport needs to consider the risks and the opportunities to control those risks and consider a helmet in that context. A helmet worn in climbing or skiing could be supplied that would offer protection to the head falling through 3 m, but it would be very challenging to offer protection in an impact equivalent to a 5 m fall. The overall survivability of the incident needs to be considered. It is well understood that as the severity of the crashes increase, motorcyclists suffer more severe injuries to a greater number of body regions. Therefore, a sport might consider that a helmet that prevents concussion and thereby permits the athlete to stay in control of the situation is more important from an overall risk management perspective than a helmet designed to protect the head from serious injury in a 5 m equivalent fall. Alternatively, in alpine skiing, preventing serious head injury may be

Table 32.2 Unique operational requirements for extreme sports helmets. All helmets require function and usability

Sports	Unique operational requirements
Snow: alpine skiing, snowboarding, free-skiing, snow skating	Materials function in extreme cold
Climbing: mountaineering, rock climbing, ice climbing	Materials function in extreme cold
	Strangulation risk with restraint system
Airborne: kite buggying, kiteboarding, snowkiting, kitesurfing, BASE jumping, skydiving, free-flying and wingsuit flying, hang-gliding, paragliding and power paragliding	Materials function in extreme cold
	Strangulation risk with restraint system
	Aerodynamic issues
Water sports: surfing, white-water canoeing and rafting, sailing and windsurfing	Materials function in the wet
	Strangulation risk with restraint system
	Potential for helmet to restrict movement in the water due to drag forces and buoyancy
	Hydrodynamic issues and concerns over 'bucketing' leading to tensile neck loads
Wheeled: skateboarding, aggressive inline, BMX, mountainboarding, downhill mountain biking	Materials function over range of temperatures, wet/dry

the desired outcome as this assists with the overall challenges of acute trauma management.

Sports might also consider opportunities to integrate safely camera, GPS and alert systems into helmets. This would mean that there was a record of an incident, not just the exciting situations, and enhance the rescue of athletes by alerting people to a head impact and the athlete's location.

Conclusions

Helmets can be designed and supplied to meet a range of requirements in sport and transport. It is important that the helmet is fit for purpose. This means that the helmet is functional and it meets the injury risk management requirements of the sport. The requirements of extreme sports may be very challenging. However, suitable helmets can be supplied based on careful consideration, a clear understanding of each sport's requirements, stakeholder consultation, industry and academic inputs. National or international standards organisations provide an opportunity to document and specify the performance requirements for helmet suppliers. The process of writing standards also forces the sport to confront clearly its objectives in terms of head protection. Sports can also prepare their own technical specifications without resorting to preparing a national standard and utilise commercial conformance and compliance bodies to ensure that helmets supplied to the sport meet the technical specifications.

References

1. Liu BC, Ivers R, Norton R, et al. Helmets for preventing injury in motorcycle riders [Review]. Cochrane Database Syst Rev. 2008;1. Retrieved January 2009 from The Cochrane Library, Wiley Interscience [Epub 24 October 2007].
2. Attewell RG, Glase K, McFadden M. Bicycle helmet efficacy: a meta-analysis. Accid Anal Prev. 2001; 33:345–52.
3. McIntosh AS, Andersen TE, Bahr R, et al. Sports helmets now and in the future. Br J Sports Med. 2011; 45:1258–65.
4. McIntosh AS. Biomechanical considerations in the design of equipment to prevent sports injury. Proc Inst Mech Eng P J Sports Eng Tech. 2012;226:193–9.
5. Newman J. The biomechanics of head trauma: head protection. In: Nahum AM, Melvin JW, editors. Accidental injury biomechanics and prevention. New York: Springer; 1993. p. 292–310.
6. Hoshizaki TB, Brien SE. The science and design of head protection in sport. Neurosurgery. 2004;55: 956–67.
7. McIntosh AS, Janda D. Cricket helmet performance evaluation and comparison with baseball and ice hockey helmets. Br J Sports Med. 2003;37:325–30.
8. McIntosh AS, Lai A, Schilter E. Bicycle helmets: head impact dynamics in helmeted and unhelmeted oblique impact tests. Traffic Inj Prev. 2013;14:501–8.
9. Aare M, Halldin P. A new laboratory rig for evaluating helmets subject to oblique impacts. Traffic Inj Prev. 2003;4:240–8.
10. Mertz MJ, Irwin AL, Prassad P. Biomechanical and scaling bases for frontal and side impact injury assessment reference values. Stapp Car Crash J. 2003;47: 155–88.
11. McIntosh AS, Patton DA, Frechede B, et al. The biomechanics of concussion in unhelmeted football players in Australia: a case-control study. BMJ Open. 2014;4:e005078. doi:10.1136/bmjopen-2014-005078.
12. McIntosh AS, Suratno B, Haley J, Truoung J. Consumer rating and assessment of safety helmets for motorcyclists, 2013. In: Proceedings of the 23rd international technical conference on the enhanced safety of vehicles, May 27–30, 2013, Seoul, Paper Number:13–0157.
13. McIntosh AS, Patton DP. Impact reconstruction from damage to pedal- and motor-cycle helmets. Proc Inst Mech Eng P J Sports Eng Tech. 2012;226:274–81.
14. Cripton PA, Dressler DM, Stuart CA, et al. Bicycle helmets are highly effective at preventing head injury during head impact: head-form accelerations and injury criteria for helmeted and unhelmeted impacts. AAP. 2014;70:1–7.

Visual Performance in Extreme Sports

33

Injury Prevention and Eye Protection

Daniel S. Morris and Sam Evans

33.1 Anatomical Considerations

The eyeball (globe) sits within the bony orbit, supported by the intra-orbital soft tissues (fat, fascia and muscle), and is covered by the two eyelids. These two anatomical regions (orbit and external eyelids) are divided by the orbital septum, a fascial layer arising from the bony orbital rim and extending to the lid margin.

The bony orbit is a quadrilateral pyramid, the apex of which is the orbital apex wherein the nerves, arteries and veins are transmitted to the middle cranial fossa. The base of the pyramid is the anterior orbital margin, which provides a varied degree of protection for the globe. This protection is most complete at the superior and medial margins. The lateral aspect of the globe is significantly exposed by the curve of the zygoma. The bone of the orbital rim is thickest superiorly (frontal bone) and thinnest inferomedially (maxilla). Internally the orbit is separated from the ethmoid sinuses medially by the thin ethmoid, lacrimal and sphenoid bones and inferiorly from the maxillary sinus by the lamina papyracea of the maxilla. The frontal sinuses sit above the orbit within the frontal bone.

The orbital apex is formed by the sphenoid, lacrimal and maxillary bone. Communication with the middle cranial fossa is via the superior and inferior orbital fissure at the apex. The extraocular muscles (except inferior oblique) and the upper lid levator muscle also arise in this area.

The wall of the eyeball is a continuous sheet of collagen fibrils arranged in a lamella fashion. Anteriorly, these form the clear cornea, which is continuous with the opaque sclera posteriorly. Vascular supply to the posterior segment (all tissues posterior to the iris) is via the highly vascularised choroid and the central retinal artery which both derive their supply from branches of the ophthalmic artery (via the internal carotid artery). Supply to the anterior segment is via arteries transmitted within the four recti muscles.

Movements of the eye are effected by the four recti and two oblique muscles. These are innervated by cranial nerves III, IV and VI, all of whose fascicles are transmitted via the orbital apex (Fig. 33.1).

The ocular surface is protected by the tear film and the eyelids. Tears are a triphasic matrix, produced by cells in the conjunctiva, lacrimal gland and lid – comprising of mucinous, aqueous and lipid phases which variously nourish, hydrate and stabilise the ocular surface. Deficiency in any of these phases may lead to degeneration of the ocular surface, which varies from mild gritty dry eyes to sight-threatening corneal ulceration.

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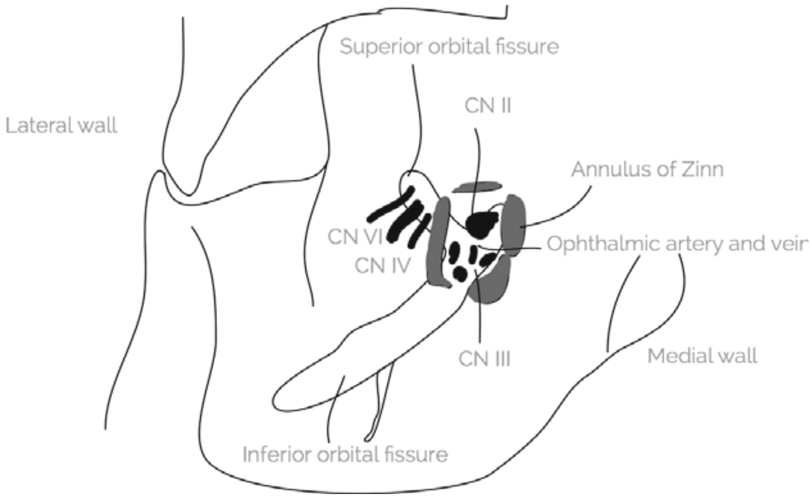

Fig. 33.1 Orbital anatomy

The eyelids provide physical protection for the ocular surface. They consist of the posterior, conjunctival surface; a central structural component (the tarsal plate) and an anterior skin/muscle lamella. The levator palpebrae superioris muscle effects upper lid closure, whilst the orbicularis oculi muscle maintains the tone of the lower lid, keeping it effaced to the globe. The blink reflex, lid closure and upward deflection of the globe on lid closure (Bell's phenomenon) all protect the ocular surface from environmental damage. An intact, smooth lid margin contour is also important in order to maintain stable tear film dynamics and healthy ocular surface.

Although the orbit and eyelids provide some degree of protection for the eye, specific points of anatomical weakness and vulnerability exist:

- The orbital apex
- Haemorrhage at the apex (retrobulbar haemorrhage) is a potentially blinding ophthalmic emergency which should be treated urgently, in the field if required (see instructions on Canthotomy and Cantholysis).
- The orbital floor
- Blowout fracture of the thin orbital floor resulting from blunt axial trauma can entrap muscle fibres of inferior rectus leading to tissue necrosis.
- The optic nerve
- Avulsion injuries to the nerve cause significant sight loss or blindness.
- The lateral side of the globe
- Bony protection of the lateral globe is poor.
- The anterior surface of the globe
- Penetrating injuries of the globe may occur, even through closed eyelids.
- The eyelids
- As the external surface of the adnexae, the eyelids are most exposed to potential traumatic injury.

33.2 Ametropia and the Correction of Refractive Error

Prevalence of refractive error varies around the world, with significantly higher rates of myopia ("short sightedness") in Asian peoples. Clinically, important refractive error causing blurring of vision (ametropia) is thought to affect half of all adults in the USA, with rates of myopia appearing to increasing [1].

Prevalence of severe myopia ("short sightedness"), defined as a spherical equivalent prescription of less than or equal to −5.00 dioptres, is more than 7 % of adults aged between 20 and 59, which is the age group most likely to undertake extreme or wilderness sporting activities. Rates of hypermetropia ("long sightedness") are lower; between 1 and 2.4 % of adults in the same age groups have a spherical equivalent of equal to or greater than

+3.00 dioptres [2]. Therefore, a large proportion of individuals undertaking extreme or wilderness sporting activities will require refractive correction. The specific visual demands of particular sporting activities may place extra requirements and result in the use of refractive correction which might not be required in normal activities.

The choice of ametropic correction depends on the degree of refractive correction required, the amount the error interferes with sporting activities, the environment in which the sport is undertaken, specific anatomical considerations and individual preference.

Refractive correction options available are:

- External correction (glasses/contact lenses)
- In-plane correction (corneal refractive surgery)
- Internal correction (phakic intraocular lens (IOL) implantation or clear lens extraction and IOL implantation)

Each has merits and limitations and may have particular considerations in the context of extreme sports:

33.2.1 Glasses

Glasses or spectacle lenses can adequately correct most refractive errors, although correction of very high and low prescriptions with glasses may induce chromatic and spherical aberrations which can be just as troublesome as the initial visual blurring. Varifocal or bifocal glasses provide excellent correction for near and distance, which is relevant in presbyopic individuals where accommodative function is reduced (over the age of 45), and are usually well tolerated.

Glasses also provide an extra physical protection for the eye and adnexa, and refractive correction may be incorporated into snow goggles, sunglasses and diving goggle lenses. Furthermore, the use of photochromatic lenses (“light reactors”) provides effective UV filtering with refractive correction.

However, glasses may become a distracting or dangerous encumbrance, in particular when their effect is negated by the environment. This is particularly the case for water sports, bungee jumping and free-fall/static line parachuting. In these cases, contact lenses may be more appropriate.

In extremis when glasses or sunglasses have been lost or broken, a pinhole punched through a piece of card or bark functions as rudimentary glasses and will allow for evacuation from remote environments; this will also serve to protect the eyes from ultraviolet light.

33.2.2 Contact Lenses

Around 5 % of the population aged between 15 and 64 wear contact lenses, the vast majority wearing soft hydrogel or daily disposable lenses [3, 4]. Contact lenses can adequately correct refractive errors of a similar range to that of glasses and are less prone to the refractive aberrations which are characteristic of higher prescriptions in glasses.

Care for contact lenses, personal hygiene and strict adherence to wear schedules and rest periods reduces the risk of serious infection related to contact lens wear, which may be blinding. These infections are over five times more likely in multi-use soft lenses than daily disposables [4], and the use of disposable lenses in preference to multi-use lenses for extreme and wilderness sports should be encouraged.

One of the major advantages of contact lenses, when compared with glasses, is that they can be used in the water. Between 52.7 and 60 % of contact lens wearers habitually use them whilst swimming or surfing [3, 5]. However, the risk of serious infection is significantly increased with this practice, in particular protozoan infection (*Acanthamoeba* spp.) which is associated with a grave visual prognosis if there is a delay to diagnosis and appropriate management [6]. The refractive and practical advantages of contact lens use for water sports are clear, but it is important to educate participants to use fresh, disposable lenses for the duration of the activity only, removing them immediately afterwards, and to seek early expert medical attention if signs of symptoms of infection appear (pain, redness or blurred vision).

33.2.3 Photorefractive Surgery (LASEK, LASIK and PRK)

Photorefractive surgery ("laser eye surgery") for the in-plane correction of ametropia and astigmatism has found a strong market in young adults who participate in extreme and wilderness sports. The risks associated with contact lens wear and the inconvenience of glasses are obviated, and in most cases, patients vision is improved to a level where participation in sports is possible.

Although laser in situ keratomileusis (LASIK) remains the most popular modality of photorefractive surgery, increasing numbers of refractive surgeons are undertaking surface ablation techniques (LASEK, PRK and sub-epithelial keratectomy) to correct low to moderate refractive error or in patients where traditional LASIK is not appropriate.

In general terms, the laser-refractive techniques can be split in into those that create a flap of healthy corneal epithelium ± superficial stroma, which is then replaced after ablation of the stromal bed, and those that ablate the surface directly or remove the epithelium before ablation. Recovery times, post-operative discomfort and infection risks are lower in the flap group (LASIK) but problems with flap/bed interface adherence, lamellar keratitis and changes in the structural integrity of the cornea (causing unpredictable refractive changes and the potential for traumatic loss of the flap) are generally not seen in the non-flap group. Most photorefractive surgery undertaken currently is LASIK, although a slow trend towards non-flap (surface ablation) techniques is well documented [7].

33.2.4 Surgical Approaches to Ametropia

Modern advances in surgical technique and implant choice have led to an increasing trend towards refractive surgery for young patients with moderate to high refractive error and especially with presbyopic patients over the age of 45. The choice of surgical techniques is wide and may involve replacement of the natural crystalline lens with a synthetic intraocular lens (IOL) (clear lens extraction) or implantation of an IOL in an eye in which the crystalline lens remains (phakic IOL implantation). The choice of approach depends on the specific refractive error and the visual requirements of the patient. IOL placement is most commonly behind the iris (either in the ciliary sulcus or the lens capsule), but the increasing use of modern anterior chamber and iris clip lenses (particularly in phakic IOL procedures) present specific considerations in the case of extreme and wilderness sports. High degrees of ametropia and astigmatism can be corrected with modern IOLs, many of which also offer a degree of multifocality or pseudo-accommodation in order to allow the pre-presbyope to continue to function without glasses.

All intraocular surgery carries risk of infection and sight loss or blindness. The structural integrity of the eye is compromised following surgery, and case reports exist of traumatic expulsion of the contents of the eye following direct trauma to the eye years after modern cataract surgery [8] although these are very much less likely with modern techniques. Ultraviolet light is absorbed by the crystalline lens but not by clear IOLs. For this reason, blue light filtering (yellow) IOLs have been developed and are in use. The evidence for significant retinal damage in patients with clear IOLs is not clear cut, and the use of these lenses should not preclude individuals from undertaking sporting activities in high ambient UV conditions, provided that suitable ocular UV protection is used.

33.3 Pre-existing Ocular Conditions

The only ocular condition which excludes ascent to high altitude or even air travel is the immediate post-operative period following the use of intraocular gas in retinal surgery as this can expand and potentially cause a central retinal artery occlusion [9].

Environmental factors may exacerbate existing ocular conditions; in particular ocular surface disease and consideration should be given to prophylaxis in these circumstances.

33.3.1 Monocular Vision

People with useful vision in only one eye should take extra care to protect their eyes from both the sun and objective dangers such as sand, ice and rock. It is therefore advisable to have specially designed polycarbonate safety glasses for any activities where flying debris could enter the eye.

33.3.2 Dry Eye

Dry eye is a multifactorial condition, which is frequently overdiagnosed and treated. However, arid and high ambient UV conditions such as those found in deserts and alpine environments may exacerbate existing disease, and there is a small risk of sight-threatening corneal ulceration in dry eye disease. It is sensible to use lubricating eye drops, especially in these adverse environmental conditions. A balance should always be struck between using a drop sufficiently viscous to give adequate benefit, without being so thick as to impair vision, and preservative-free drops should be used in contact lens wearers.

33.3.3 Cataract Surgery

There are no special precautions required for people who have an intraocular lens following cataract surgery or clear lens extraction who want to partake in extreme sports. Whilst no studies have been undertaken to establish the safety of extreme sports in pseudophakic patients, there is plenty of anecdotal evidence from extreme sportspeople, mountaineers, aviators and even astronauts.

33.3.4 Glaucoma

People on topical medication (drops) to reduce their intraocular pressure (IOP) in glaucoma should continue them as normal. There is no evidence to suggest that people with glaucoma cannot partake in extreme sports, but a full eye check is recommended before travel for any length of time, especially to high altitude. Acetazolamide (Diamox) used for the prophylaxis or treatment of acute mountain sickness in glaucoma patients could have a double effect as it significantly lowers IOP.

There is still debate as to the effect of high altitude on IOP; with some groups showing a decrease [10, 11], others have found normal IOP [12] and even a reduction in IOP that occurred within hours of ascent and then recovered during acclimatisation [13, 14].

33.3.5 Diabetes

Diabetes mellitus is not a contraindication to extreme sports. However, each individual will need to be more vigilant of his or her blood glucose levels when partaking in sporting activity. Advice should be sought about the best method for glycaemic control depending on the anticipated activity together with how often blood sugar should be checked, and other people partaking in sport with diabetics should be aware of the signs of hypoglycaemia and its treatment.

There is no evidence that high altitude causes or exacerbates diabetic retinopathy [15]. Diabetic people also do not appear to be at any greater risk of high-altitude retinopathy. However, diabetics should maintain strict glycaemic control and acclimatise sensibly to avoid systemic or ocular consequences.

33.3.6 Retinal Surgery

There is some evidence that retinal detachment may be induced at high altitude [16] in susceptible individuals, but once a detachment has been repaired successfully, there should be no risk at altitude. However, if a person has recently had retinal surgery with intraocular gas, they should not go into any environment where atmospheric pressure is changed: this includes air travel, high altitude and SCUBA diving. People should not travel by air until the intraocular gas has been absorbed; this can be more than a month. Silicone oil in the eye or retinal buckle surgery is not contraindications to air travel. People who have had recent retinal surgery should consult their ophthalmologist for advice on travel.

33.4 Extreme Sports at High Altitude (Hypobaria)

Extreme sports undertaken at altitude include mountaineering, high-altitude trekking, snow sports, hang gliding, paragliding and parachuting.

In general, the risks to ocular health at altitude are those related to the environment. Low atmospheric oxygen concentrations, high ambient ultraviolet radiation levels, low temperatures and co-morbid physiological changes (such as acute mountain sickness) may all have an effect on ocular health.

33.4.1 UV Exposure

High ambient UV radiation, in particular UV-A (320–400 nm) and UV-B (290–320 nm), is known to be carcinogenic, and whilst UV-B has historically been considered to have the greatest effect, increasing evidence suggests a key role for UV-A in tumour development. Skin tumours of the eyelids and adnexae comprise 5–10 % of all skin cancers – most of these are basal cell carcinoma (BCC) or squamous cell carcinoma (SCC). Indeed, non-melanoma skin cancer is the most commonly diagnosed tumour in men in the USA [17]. Increasing rates of outdoor sports participation and thinning of the ozone layer have been associated with growing rates of cutaneous melanoma particularly in high latitudes; the rates in more temperate parts of the world have stabilised – probably due to improved understanding, education and prevention. The risk of skin cancers of this type is known to be dose dependent, and thus short periods of time spent at altitude, for example, during parachuting are unlikely to carry a significantly increased risk. There is good evidence to back up theories that long-term high-altitude activities are a positive predictor for developing skin cancer and precancerous disease (solar keratosis) [18]. Significant episodes of sunburn are associated with increased rates of BCC, and so prudent UV-A/B protection should be practised in these environments with sun-protective clothing, sunglasses, hats and judicious use of sunscreen and lip balm [18, 19].

33.4.2 Snow Blindness

Snow blindness is characterised by red, gritty, painful eyes with reduced vision and photophobia. It is caused by unprotected exposure of the cornea and conjunctiva to high UV-B radiation and is an important cause of ocular morbidity in high-altitude environments. The consequences of this condition may be grave for the health and safety of the individual or team, and its prevention should be taken seriously. Having occurred, snow blindness should be treated with cool compresses, lubrication with artificial tears (unpreserved where possible), antibiotic ointment (e.g. Oc. chloramphenicol tds) and rest with light avoidance. Recovery usually starts within 24 h, but the risk of secondary bacterial infection persists. Although the relief they offer is striking, topical local anaesthetic drops should not be used regularly as they slow corneal healing and re-epithelialisation. Where these drops are used for initial examination, the eye should be double padded for 6 h with antibiotic ointment.

Prevention is far better than cure when it comes to snow blindness. Appropriate UV-filtering sunglasses (with side pieces) or goggles should be mandatory in the mountains. These should meet CE/EN protection class 3 or 4 (100 % UV protection).

33.4.3 High-Altitude Retinopathy (HAR)

Retinal and disc vascular changes at altitude have been recognised for years, although it is only recently that sufficiently portable and reliable imaging systems have been available to document them in the field. There is a spectrum of vasculopathy seen at altitude, from scattered retinal haemorrhages to the appearance of disc oedema and cotton wool spots, defined as high-altitude retinopathy (HAR) (Fig. 33.2). HAR is seen in approximately one third of lowlanders ascending above 2500 m but is usually asymptomatic [20, 21]. It is characterised by retinal vascular tortuosity, dilatation and superficial retinal haemorrhages, frequently without sig-

Fig. 33.2 High-altitude retinopathy showing vascular engorgement and multiple superficial retinal haemorrhages

nificant visual impairment, which resolve entirely on return to lower altitude. Near-linear increases in retinal blood vessel calibre, vascular tortuosity and retinal blood flow are seen during normal climbing profiles up to 6800 above sea level [22].

Blood flow velocity in the choroidal circulation is not subject to the same autoregulatory mechanisms and does not increase in the same fashion, demonstrating the twin circulation of the posterior segment. Nevertheless, systemic changes in physiology, in particular the significant increase in haematocrit under hypoxaemic conditions at altitude and consequently increased plasma viscosity, increase the risk of venous stasis and occlusion with or without macular oedema [21]. The putative mechanisms of HAR, HACE, HAPE and AMS are similar, and circumstantial evidence does point to an increased incidence of HAPE and HACE in climbers with severe HAR [21]. The effect of altitude on macular function and anatomy is not well understood. Whilst most mountaineers do not suffer from significant visual disability due to macular dysfunction, multifocal electroretinogram (mf-ERG) has been demonstrated to be reversibly reduced whilst at altitude [23].

Treatment for HAR is not well studied; although the effects on vision are limited in most cases, occasionally loss of central vision occurs due to a macular haemorrhage, and there are anecdotal reports of intra-retinal bleeds being drained surgically. In general terms, symptomatic HAR should be treated in the same way as AMS with rest, oxygen and descent if necessary.

33.4.4 Corneal Freezing and Desiccation Keratitis

High-altitude free-fall parachuting exposes participants to freezing temperatures and high wind speeds. These conditions present a risk of corneal freezing and desiccation keratitis. For this reason, the use of protective goggles is mandatory; however, these may be displaced, particularly in less experienced parachutists, resulting in ocular symptoms in up to 69 % of parachutists who reported goggle loss [24]. The use of contact lenses is not protective in goggle less free fall. The rates of corneal injury are significantly reduced in the nonfreezing conditions usually experienced in recreational free fall, when compared with higher-altitude military free-fall profiles, in particular corneal desiccation and freeze-thaw injury.

33.5 Underwater Extreme Sports

Recreational SCUBA diving is one of the most popular sports in the world with around 3 million participants in the USA in 2012 [25]. Highly structured training by national organisations, including PADI, NAUI and BSAC, and regulatory bodies such as the Divers Alert Network (DAN) ensure a remarkably low rate of serious adverse health effects in participants. However, the hyperbaric environment exposes individuals to specific risks, many of which have ophthalmic manifestations. The main risks are:

1. Decompression sickness
   Arterial gas embolism
   - Oxygen toxicity

These should be considered as all belonging to a common pathophysiological spectrum.

33.5.1 Decompression Illness

Decompression sickness and acute gas embolism constitute decompression illness and are characterised by the formation of bubbles of decompressing gases within the bloodstream and tissues. The most common cause for decompression illness is rapid or inappropriate ascent from depth, although it may also occur during rapid escape from a hyperbaric environment (usually in an industrial context), or rapid ascent to altitude in a non-pressurised aircraft.

33.5.2 Decompression Sickness (DCS)

Decompression sickness is caused by the formation of nitrogen gas bubbles in the tissues and bloodstream of a diver as they ascend from depth. These bubbles are present in all divers, although not all develop DCS, whose manifestations are mainly physiological – increasing understanding of the biochemical consequences of nitrogen gas bubbles has led to better prevention and early detection and treatment.

The systemic effects of DCS vary from mild skin itch to life-threatening pulmonary and cardiovascular collapse. The ophthalmic manifestations of the condition are a reflection of central neurological insult. Symptoms such as transient scotoma, visual disturbance and tunnel vision have been reported.

33.5.3 Arterial Gas Embolisation (AGE)

At the most severe end of the DCS spectrum, AGE represents the phenomenon of large bubbles of Nitrogen gas freely moving within, and occluding, arteries. This may cause circulatory collapse or stroke, particularly in the context of a patent foramen ovale causing a left to right shunt. Acute central retinal artery occlusion (CRAO) may be caused by gas emboli and is characterised by sudden, painless loss of vision to very low levels (hand movements or worse). Examination may demonstrate a relative afferent pupillary defect (RAPD) and the appearance of a “cherry red spot” at the macula. All retinal arterioles appear thready, and the entire retina is pale. Visual prognosis is grave unless central retinal artery perfusion can be reinstated within 20 minutes. In the context of AGE/DCS, this can only be achieved with recompression – the delay to this therapy is likely to be too long to effect reperfusion. Outside of the hyperbaric setting CRAO is usually a thromboembolic event; efforts to achieve reperfusion include rebreathing expired carbon dioxide with a paper bag, thrombolysis and vigorous ocular massage. Whilst these techniques can be attempted in the AGE setting, their effect (already fairly limited) is unlikely to be successful.

Occlusion and ischaemia of the choroidal circulation are less likely to cause acute loss of vision, but signs including blot haemorrhages, cotton wool spots and macula oedema may be manifested in the fullness of time.

33.6 Ocular Trauma in the Extreme Sport Setting

33.6.1 Corneal Abrasion

A corneal abrasion is a tear in the corneal epithelium, usually through mild trauma, such as removing a contact lens or perhaps even whilst asleep. It is exquisitely painful, and topical anaesthetic will provide immediate relief but should not be used as a treatment as topical anaesthetic drops delay corneal epithelial healing and prevent the patient from knowing whether they are touching their cornea or if their condition is getting worse through increased pain. Fluorescein will confirm that the diagnosis and treatment are with antibiotic drops or ointment. An eye pad is not usually necessary and may encourage infection.

33.6.2 Corneal Foreign Body

Occasionally, the protective blink reflex fails and allows a foreign body to embed itself into the cornea. This can be metallic or organic, and a metallic foreign body will often leave a rust ring. The mechanism of injury should be ascertained as a high-velocity foreign body that is more likely to penetrate the globe (such as a shard of metal from an ice axe).

A corneal foreign body will cause a red, painful gritty eye and the sensation that something is in the eye. The foreign body is usually very small but fluorescein and a magnifying loupe can assist identification and removal, either with a cotton bud or a 25G needle. Patients should then be given antibiotic ointment (e.g. Oc chloramphenicol ointment tds). Eversion of the upper eyelid should be performed to exclude a sub-tarsal foreign body.

33.6.3 Chemical Injury

A chemical splash can be sight threatening and therefore should be immediately and comprehensively irrigated, preferably with sterile normal saline. Check the pH with litmus paper if available and continue irrigation until pH is 7. Any neutral pH liquid can be used for irrigation (with the possible exception of milk), and irrigation may need to be performed for many hours to remove the offending chemical. Irrigation can be painful, but it is important to persist; topical anaesthesia may help the patient tolerate the procedure.

It is important to identify the chemical; alkali penetrates the ocular tissues much faster than acid and therefore has a worse prognosis. Treatment should include antibiotic ointment (e.g. chloramphenicol tds), lubrication (e.g. artificial tears hourly) and cycloplegic drops (e.g. cyclopentolate tds) for pain relief. Note that a *white* eye in the acute phase could indicate severe ischaemia. Chemical eye injuries are sight threatening, and the patient should be evacuated for specialist treatment.

33.6.4 Eyelid Laceration

The eyelids play an important role in protecting the eye and preventing corneal desiccation. If they are damaged, the eye can be rendered vulnerable. The underlying eye should always be checked for a penetrating injury to the globe, especially if the mechanism of injury was of high velocity. The wound should be examined carefully and cleaned if necessary. If the lid margin is interrupted and the ends are not opposed, primary repair under local anaesthesia should be considered. This is especially important with the upper lid to prevent corneal exposure. If repair is not possible, apply plenty of antibiotic ointment (e.g. Oc chloramphenicol tds) and patch the eye if you are concerned about exposure before arranging evacuation.

33.6.5 Penetrating Eye Injury

A penetrating eye injury involves disruption of the globe integrity and is a serious, sight-threatening problem. In the wilderness setting, a penetrating injury may be sustained from hammering a metal peg, a chip of rock, a tree branch, a walking pole or even a fishing hook. The mechanism of injury is important in determining whether there could be an intraocular foreign body or a perforating injury (entry and exit). A high suspicion of penetrating injury should be maintained in any high-velocity high injury, such as those involving firearms, explosions or hammering. Signs of perforating or penetrating injury include decreased vision, a soft watery eye (gently compare the pressure of both eyes with your thumbs – there is a risk of causing catastrophic expulsion of the ocular contents with this manoeuvre, and it should be avoided if possible), a peaked pupil (i.e. not round) and expulsion of ocular contents.

Any suspected penetrating eye injury should be immediately evacuated for specialist treatment. Broad-spectrum systemic antibiotics should be started, and any expulsed ocular contents should not be touched; antibiotic ointment and a pad should be applied to the eye.

33.6.6 Blowout Fracture and Blunt Trauma

Blunt trauma to the globe (e.g. from a fall or a punch) can cause the bony orbital floor to fracture tethering the inferior rectus muscle and limiting upgaze. This causes double vision, a sunken eye and pain on eye movement. The double vision may be intolerable in which case the

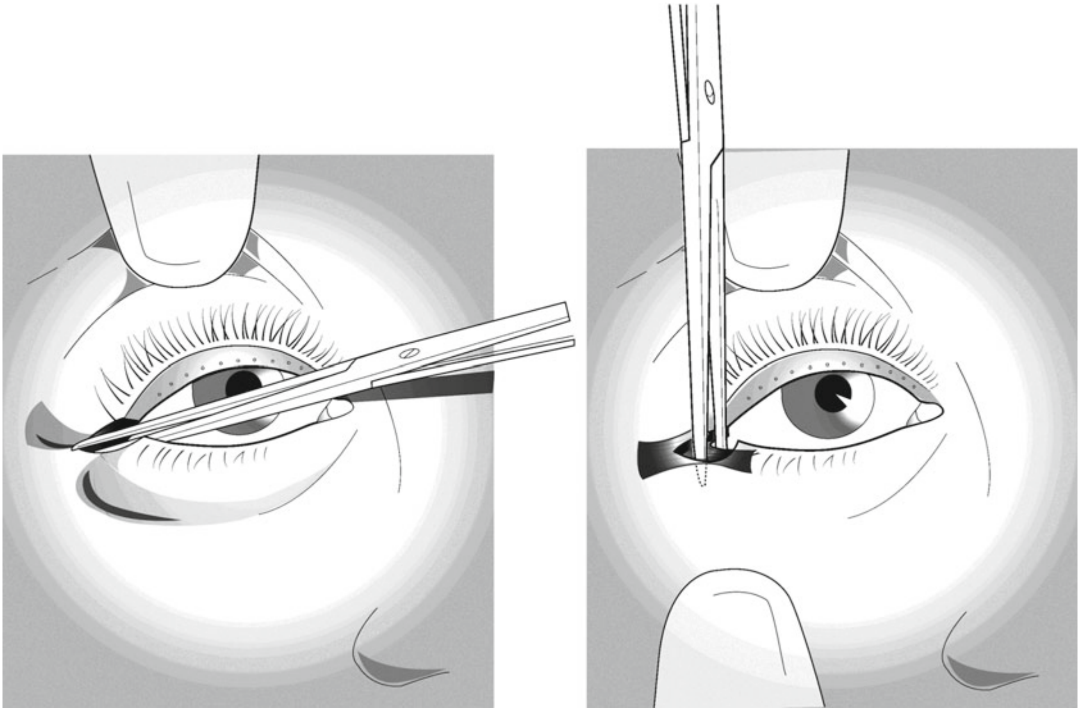

Fig. 33.3 Lateral canthotomy and cantholysis for orbital compartment syndrome

damaged eye should be patched. Remember that blunt trauma can cause many other problems within the eye, such as hyphema, subluxed lens, vitreous haemorrhage, retinal detachment and globe rupture. If visual acuity is decreased, consider evacuation for specialist evaluation.

33.6.7 Orbital Compartment Syndrome

The orbit is a relatively closed compartment with limited ability to expand, so orbital pressure can rise rapidly when an acute rise in orbital volume occurs. This is an emergency where prompt simple treatment can prevent blindness.

The most common cause of orbital compartment syndrome is retrobulbar haemorrhage in the context of trauma, especially in the wilderness setting, but spontaneous retrobulbar haemorrhage can also occur due to venous anomalies, intra-orbital aneurysms and malignant hypertension. Severe orbital cellulitis with an abscess can also cause an orbital compartment syndrome. Patients with increased orbital pressure present with pain causing vomiting, proptosis, red and swollen conjunctiva, limited eye movements and decreased optic nerve function (decreased vision and an afferent pupillary defect).

Treatment is with a surgical lateral canthotomy and cantholysis to release the pressure. This is a relatively straightforward procedure that can be performed as an emergency procedure under local anaesthesia if evacuation is not possible. The lower eyelid is completely detached from the lateral orbital rim using scissors, first horizontally to cut through the lateral canthal angle (canthotomy) and then vertically to cut the lateral canthal tendon (Fig. 33.3). If the lid is held with forceps, it is possible to feel when the tendon has been severed. The patient should then be evacuated for specialist evaluation and treatment.

33.7 Ocular Protection in Extreme Sports

Prevention of injury to the eye or adnexal structures should be considered mandatory during extreme sporting activities and on expeditions to any wilderness area.

A risk assessment, whether formal or informal, should be performed, with particular reference to those anticipated activities where potential injury or damage to the eye may occur.

The specific protection mechanism should be considered in the context of the likelihood of the risk, the effect of that damage in that environment and the implications of the protective measures.

In general, when undertaking activities at altitude or in climates with high ambient UV radiation, certified UV-protective eyewear should be worn. Specific international standards for this eyewear are discussed below. Where there is risk of blast injury, eyewear should be chosen which is designed and manufactured to protect against these injuries.

Wraparound or goggle fit lenses provide the highest level of protection and should be considered in high-UV environments as well as those where projectiles may be encountered.

Where concern exists about the integrity of the eye after an injury has been sustained, serious thought should be given to evacuating the patient to a specialist care centre.

33.7.1 Mechanical Eye Protection

Spectacle and goggle lenses are regulated in terms of mechanical strength and filtering properties. In Europe, the mechanical protection requirements are established in European standard EN 166:2002. Standards relating to transmission filters are also governed by European legislation [26].

The standards applied to sunglasses (BS EN 1836:2005 and A1:2007) cover glare filters for general use sunglasses. Specific tint and reflective covering options are available, which may improve resolution of fast-moving objects (e.g. cricket balls) in certain situations. Lenses made from polycarbonate filter all UV at 380 nm. Tinted filters are graded 0–4, after ABDO guidance [26] (Table 33.1).

Table 33.1 Classification of tinted filters [26]

Grade	Description	Luminous transmittance range	
		From (%)	To (%)
0	Clear/light tint	80	100
1	Light tint	43	80
2	Medium tint	18	43
3	Dark tint	8	18
4	Very dark tint	3	8

Conclusion

Good vision is vital for safety and performance when undertaking extreme sports. However, the effect of different environments and altered physiology on the eye is often taken for granted, as is health of the eyes. This chapter will hopefully make health professionals and participants more aware of potential sporting and environmental hazards, how injury can be avoided but also how it can be treated. Prevention is always better than cure.

Bibliography

1. Dayan BY, Levin A, Morad Y, Grotto I, Ben-David R, Goldberg A, Onn E, Avni I, Levi Y, Benyamini OG. The changing prevalence of myopia in young adults: a 13-year series of population-based prevalence surveys. Invest Ophthalmol Vis Sci. 2005;46(8):2760–5.
2. Vitale S, Ellwein L, Cotch MF, Ferris FL, Sperduto R. Prevalence of refractive error in the United States, 1999–2004. Arch Ophthalmol. 2008;126(8):111–1119.
3. Edwards K, et al. The penetrance and characteristics of contact lens wear in Australia. Clin Exp Optom. 2014;97(1):48–54.
4. Stapleton F, et al. The incidence of contact lens–related microbial keratitis in Australia. Ophthalmology. 2008;115(10):1655–62.
5. Wu Y, et al. Contact lens user profile, attitudes and level of compliance to lens care. Cont Lens Anterior Eye. 2010;33(4):183–8.
6. Claerhout I, et al. Delay in diagnosis and outcome of Acanthamoeba keratitis. Graefes Arch Clin Exp Ophthalmol. 2004;242(8):648–53.
7. ISRS survey 2014. http://www.aao.org/isrs/resources/us-trends-survey-2012.cfm.
8. Walker NJ, Foster A, Apel A. Traumatic expulsive iridodialysis after small-incision sutureless cataract surgery. J Cataract Refract Surg. 2004;30(10):2223–4.
9. Polk JD, Rugaber C, Kohn G, Arenstein R, Fallon Jr WR. Central retinal artery occlusion by proxy: a cause for sudden blindness in an airline passenger. Aviat Space Environ Med. 2002;73(4):385–7.
10. Somner JEA, Morris DS, Scott KM, MacCormick IJC, Aspinall P. What happens to intraocular pressure at high altitude? Invest Ophthalmol Vis Sci. 2007;48(4):1622–6.
11. Brichman-Hansen O, Myhre K. Blood pressure, intraocular pressure and retinal vessels after high altitude

mountain exposure. Aviat Space Environ Med. 1989;60(10):970–6.
12. Clarke C, Duff J. Mountain sickness, retinal haemorrhages, and acclimatisation on Mount Everest in 1975. Br Med J. 1976;2(6034):495–7.
13. Cymerman A, Rock PB, Muza SR, Lyons TP, Fulco CS, Mazzeo RS, Butterfield G, Moore LG. Intraocular pressure and acclimatization to 4300 M altitude. Aviat Space Environ Med. 2000;71(10):1045–50.
14. Pavlidis M, Stupp T, Georgalas I, Georgiadou E, Moschos M, Thanos S. Intraocular pressure changes during high-altitude acclimatization. Graefes Arch Clin Exp Ophthalmol. 2006;244(3):298–304.
15. Leal C, Admetlla J, Viscor G. Diabetic retinopathy at high altitude. High Alt Med Biol. 2008;9(1):24–7.
16. Morris DS, Severn PS, Smith J, Somner JEA, Stannard KP, Cottrell DG. High altitude and retinal detachment. High Alt Med Biol. 2007;8(4):337–9.
17. Leiter U, Garbe C. Epidemiology of melanoma and nonmelanoma skin cancer – the role of sunlight. Adv Exp Med Biol. 2008;624(8):89–103.
18. Moehrie M. Outdoor sports and skin cancer. Clin Dermatol. 2008;26(1):12–5.
19. Kricker A, Armstrong BK, English DR, Heenan PJ. Does intermittent sun exposure cause basal cell carcinoma? A case control study in Western Australia. Int J Cancer. 1995;60(4):489–94.
20. Ho TY, Kao WF, Lee SM, Lin PK, Chen JJ, Liu JH. High altitude retinopathy after climbing mount Aconcagua in a group of experienced climbers. Retina. 2011;31(8):2650–5.
21. Arora R, Jha KN, Sathian B. Retinal changes in various altitude illnesses. Singapore Med J. 2011;52(9): 685–8.
22. Bosch MM, Merz TM, Barthelmes D, Petrig BL, Truffer F, Bloch KE, Turk A, Maggiorini M, Hess T, Schoch OD, Hefti U, Sutter FK, Pichler J, Huber A, Landau K. New insights into ocular blood flow at very high altitudes. J Appl Physiol. 2009;06(2):454–60.
23. Pavlidis M, Stupp T, Geoegalas I, Georgiadou E, Moschos M, Thanos S. Multifocal electroretinography changes in the macula at high altitude: a report of three cases. Ophthalmologica. 2005;219(6):404–12.
24. Gruppo L, Mader TH, Wedmore I. Ocular problems in military free fall parachutists. Mil Med. 2002; 167(10):797–800.
25. http://www.statista.com/statistics/191304/participants-in-scuba-diving-in-the-us-since-2006/.
26. Association of British Dispensing Opticians. Eye protection: safety and protective eyewear; 2012.

Rehabilitation of Extreme Sports Injuries

34

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34.1 Rehabilitation of Extreme Sport Athletes

A detailed description of rehabilitation tactics is beyond the scope of this chapter and has been described in further detail elsewhere in literature: this paper will therefore focus on a number of specific aspects relative to the type of exercises and the progression of the rehabilitative process for athletes who practice extreme sports. While extreme sport athletes can present with a myriad of conditions that can be rehabilitated and evaluated, for the scope of this chapter we have chosen to focus our attention on four conditions, commonly encountered in these athletes. For the purposes of selection we evaluated concussion, acute anterior glenohumeral dislocations, acute low back pain and the conservative and post-operative management of anterior cruciate ligament compromise in the knee.

Extreme sport athletes have special considerations that may not be applied to general population and although literature is limited, generalization from athletic research can be applied. In each area, diagnosis and evaluation are briefly discussed before transitioning into common rehabilitation principles. All injury sites maintain a common theme and most treatment principles are appreciated throughout the chapter. For example, patients are ruled in for appropriate management in a physical therapists' office and, if necessary, are referred for surgical consultation. Either once returned post-operatively, or maintained in office non-operatively, principles and treatments should match goals of the athlete. These goals are broken down into primary principles of evaluating impairments and how they relate to participation limitations. Best available evidence based treatments are implemented originally to reduce and manage pain, inflammation and psychosocial impairments. These are then advanced to progression of improving range of motion, strength/stability, with final phase of evaluating movement behaviors in area of interest. Finally, protection of injury site is evaluated in breaking down extreme athlete environment and qualitatively and quantitatively evaluated by a team of providers.

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Lastly to be noted, continued communication and cooperation between all fields of athlete management are imperative including: athletic trainers, physical therapist (physiotherapist), surgeons, primary care physicians, sports physicians, chiropractors and sports psychologist. As this team works together to manage the extreme sport athlete's care they match their treatment plans to the goals of the athlete and this is maintained as the common thread throughout management of the injury.

34.2 Concussion

A concussion is a transient disturbance of brain function that may be caused by either a direct impact to the neck or head or by a blow to another part of the body, with a force transmitted to the head [1]. The resultant neurological symptoms are brief, may or may not involve a loss of consciousness, and often resolve within 10 days without any focal treatment [1, 2]. Diagnosing and managing a concussion can be challenging, as signs and symptoms can be vague, delayed, and difficult to interpret. In fact, according to the 4th International Conference on Concussion in Sport in 2012, "Concussion is considered to be among the most complex injuries in sports medicine to diagnose, assess, and manage" [1]. Concussion is the principal diagnostic term used by sport medicine organizations even if, unfortunately, there is a lack of uniformity about the definition of concussion and about the management after concussion [3].

In extreme sports, both injuries of the brain and spinal cord may occur as a consequence of an incident. Concussions can occur when either a linear or rotational force is transmitted to the head; typically when the brain is subjected to an abrupt change in momentum. Further treatment, observation and rehabilitation are dependent on the extent and seriousness of such injuries.

Epidemiological data is scarce, as concussions are not always reported, especially in this population. Athletes of extreme sport have high risk for such injuries [4, 5]; Bridges et al., identified out of 1332 reported injuries, concussions accounted for 6 % in snowblading, 10 % in skiers and 15 % in snowboarders [6, 7]. Head injuries are common in surfing, kitesurfing and personal watercraft riding [7] and concussions can also be caused by a strike from the board or boom while windsurfing [8].

Sulheim et al. [9], found helmet use reduced brain injury risk by 60 % and helmet use can reduce risk of severe traumatic head injuries in a population where high velocities are present and traumatic brain injuries are of concern. Although the use of helmets may not stop a concussion, it may reduce the severity of one, which is of great importance in extreme sports [9, 10].

34.2.1 Diagnosis

"At present, there is no perfect diagnostic test or marker that clinicians can rely on for immediate diagnosis of concussion in the sporting environment" [1].

To help differentiate between concussions and more serious head trauma, a thorough clinical examination, and potential radiological examination may be necessary if a more serious brain injury is suspected. Because a concussion is a functional injury, versus a structural one, imaging such as a magnetic resonance imaging (MRI) or computed tomography (CT) scan do little to aid in the diagnosis of a concussion. A clinical examination focusing on several domains such as: patient symptoms, physical signs, behavior changes, cognitive impairment, and sleep disturbance aid in the diagnosis of a concussion [1]. This examination is important even if the patient appears stable immediately after an injury, as clinical signs can develop early on, or several hours after the injury [1].

More specifically, the signs and symptoms of a concussion may be physical (i.e.,: brief loss of consciousness, headache, dizziness, balance problems, nausea, vomiting, visual disturbances, etc.), cognitive (i.e.,: difficulty concentrating, difficulty remembering, feeling slowed down, forgetful of recent events, etc.); emotional (i.e.,: irritability, sadness, anxiety, etc.) or affecting sleep (i.e.,: drowsiness, excessive sleepiness, difficulty sleeping, difficulty falling asleep) [11].

In the extreme sport population, the diagnosis of concussion can be even more challenging. This population often practice in high altitude or deep water which can cause similar symptoms and complaints as can a concussion. The exposure to these extreme environmental conditions can also contribute to cognitive deficits such as ischemia, nitrogen narcosis [12], and hypoxia [13].

During the assessment, physicians may use one of the many concussion inventories available to help track and identify symptoms of concussion (i.e., Graded Symptom Checklist [14], Head Injury Scale [15], Sport Concussion Assessment Tool 3 (SCAT – 3) ??[1], PCSS (Post Concussion Symptom Score), or the Concussion Symptom Inventory [1, 14, 16]).

Cognitive function is evaluated by a neuropsychologist with comparative data from a pre-injury baseline, and can help with the diagnosis of a concussion. At times, baseline information is not available for reference, and a valid alternative may be the Standardized Assessment of Concussion (SAC): a 5-min mental-status screening test that evaluates orientation, immediate memory, concentration, and delayed recall [14, 17–19]. Further assessment, treatment, observation and rehabilitation of concussion are dependent on the extent of symptoms.

34.2.2 Management and Rehabilitation

Generally concussions resolve within 10 days of injury, although 10–15 % of patients develop more delayed recovery [1, 20]. Those athletes who show a slow recovery (>10 days) should be managed with a multidisciplinary team of health care professional with experience and expertise in sports-related concussion. Premature return to sport after concussion may increase the sport-related injury rates secondary to impairments associated with concussions (i.e., vestibular discrepancies, occulomotor impairments, etc.). In addition, a new head trauma while cerebral metabolism is still impaired from the previous concussion may result in second impact syndrome, a detrimental and often deadly situation [14, 21]. Therefore, the following steps are implemented to reduce premature return to sport.

Once the athlete is asymptomatic or has returned to their baseline measures (if available) a gradual return to sport progression may be started. Generally each step lasts 24 h and the entire program of graduated return to sport can be completed in a week; however depending on the individual responses it may require a longer and more gradual progression and can last for months. In particular athletes with more severe symptoms initially, or a past medical history of multiple concussions, often require longer recovery times. Ultimately, if symptoms occur in any of the steps of the return to the sport program, the athlete should return to the previous asymptomatic level and wait another 24 h before progressing again [14].

The first step involves symptom-limited physical and cognitive rest. The second step involves increasing heart rate with light aerobic exercise such as stationary cycling, walking or swimming with intensity remaining under 70 % of the maximum permitted heart rate. Resistance training should be avoided in this phase [14].

The third step includes replicating the patient's sport to identify the complexity of their needs in a controlled environment [14]. The fourth step aims to improve cognitive load, coordination, and resistance.

The objective of the fifth step is to return to training or practice for the discipline with normal workloads. The final step is the return to sport: before return to extreme sports, it is mandatory to restore confidence and to assess functional skills [14]. The decision to return-to-sport after concussion is complex, it depends on motivation and extent of injuries: it is always best individualized for the patient [22] and this is especially true in extreme sports. In fact potentially high-risk activities such as extreme sports or contact or collision sports are listed among factors that may modify the risk of concussion and duration of recovery [14].

During the rehabilitation process balance between progression and sensible consideration to not overload sensory and motor systems is imperative [3]. If the athlete is having difficulty progressing through the return to sport protocol, specialized rehabilitation focusing on the vestibular and ocular motor systems has been shown to be affective [23]. The vestibular/ocular motor screening (VOMS) assessment can help clinicians identify which patients would benefit from vestibular and ocular motor retraining to help

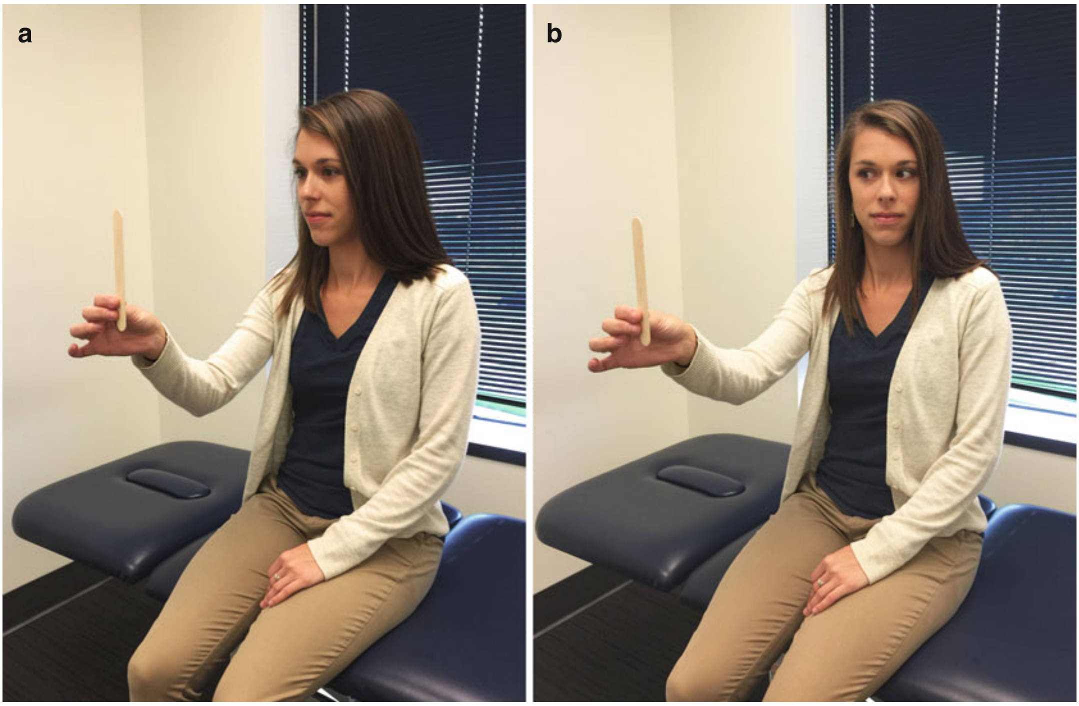

Fig. 34.1 (**a**, **b**) Vestibular retraining (VOR, horizontal canal)

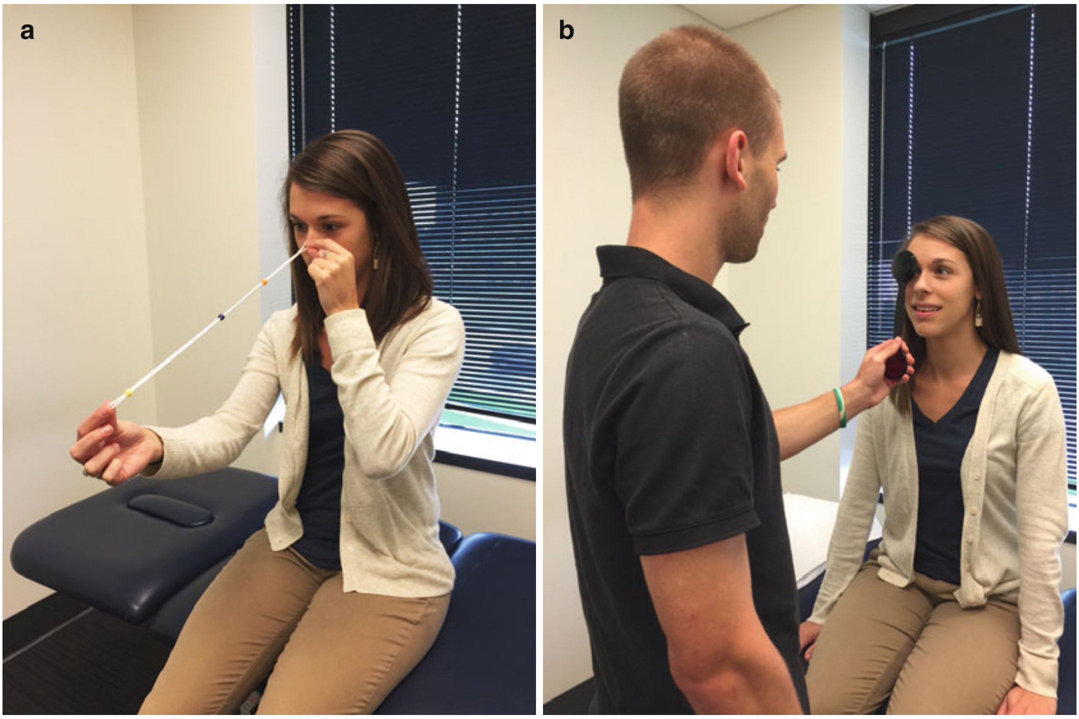

Fig. 34.2 Oculomotor retraining. (**a**) Convergence; (**b**) unilateral ocular focus retraining

facilitate their recovery (Figs. 34.1 and 34.2). [23] For this rehabilitation, clinicians specializing in the vestibular system may be able to assist athletes through a series of exercises to help decrease their overall symptoms of dizziness, fogginess, headache etc. Cervical management is also of great importance in concussion rehabilitation. Evaluation of concurrent whiplash associated disorders is essential in this population. Specifically, assessing the upper cervical spine and its possible contribution to symptoms, such as headache, pain, and cervicogenic dizziness can help enhance recovery from this injury. If an athlete is experiencing a protracted recovery, a thorough evaluation focusing on the vestibular system, neck, and tolerance to exertion can help tease out underlying impairments that may be hindering the overall recovery.

Concussion management can be daunting for both the medical professional and the extreme sports athlete. This area continues to be a focal point for research. As more evidence and information is produced regarding management, clinicians as well as the athlete will feel more comfortable and confident working through the evaluation and rehabilitation process. There is evidence pointing us in the direction of a strong clinical examination to aid our diagnosis, a thorough step wise return to activity and sport, and cervicovestibular rehabilitation if symptoms are protracted [24]. We can use this information to better assess, and assist the extreme sport athlete to full recovery after a concussion.

34.3 Shoulder Dislocation

Shoulder dislocation is common in several extreme sports, including windsurfing, surfing, snowboarding, skiing and kayaking [25–30]. As with most shoulder dislocations, the anterior variety appears to be the most common [31]. Traumatic anterior shoulder dislocation (ASD) commonly occurs with the arm in abduction and external rotation and leads to predictable anatomic injuries (Table 34.1). Generally, a combination of shoulder abduction with external rotation and extension can lever the humeral head out of the glenoid fossa and dislocate the shoulder. Extension of the elbow also increases the force transmitted along the arm, increasing the risk of wrenching the humeral head out of the glenoid fossa [32–34].

Table 34.1 Pattern of injuries associated with traumatic anterior shoulder dislocation [45–55]

Injury	Description
Bankart lesion	Avulsion injury of the labrum ± capsular injury inferior to the equator of the glenoid
Anterior labral periosteal sleeve avulsion (ALPSA)	Lesion of the anterior band of the inferior glenohumeral ligament, the labrum, and the anterior scapular periosteum
HAGL lesion	Humeral avulsion of the glenohumeral ligament
IGHL damage	Plastic deformation or tear ± complete mid-substance tears of the capsule
Glenoid rim fracture	Shear fracture or avulsion fracture of the IGHL attachment
Hill-Sachs fracture	Impression fracture of the posterosuperolateral humeral head
Greater tuberosity fracture	Fracture of greater tuberosity of humerus – serves as the insertion site of the rotator cuff tendons
Rotator cuff tear	Full- or partial-thickness tendon tear to one or more of four muscular divisions: (a) the subscapularis, (b) the supraspinatus, (c) the teres minor, and (d) the infraspinatus

Examples in pertinent sports are the following: in kitesurfing and wakeboarding shoulder dislocations are generally the result of unsuccessful tricks and jumps, in particular handle pass maneuvers [35, 36]. ASD is the most common upper extremity injury in windsurfing, usually caused by hanging onto a boom during a fall. Among skiers and snowboarders, shoulder dislocation is usually a consequence of a fall onto an outstretched hand with an element of rotation [29, 30]. In surfing, shoulder dislocation usually occurs while paddling with a poor, wide armed technique or in rough water [38–43]. In white water paddle sports, strenuous high brace supports to avoid capsizing have been associated with traumatic ASD as poor high brace technique is considered to make the shoulder vulnerable [31, 41].

Also, in skydiving a threat to the shoulder joint stability may depend on “swimming around in thick fluid airstreams” [43].

34.3.1 Diagnosis and Management

It is always important to obtain an accurate history and examination to assess the presence of intrinsic and extrinsic factors that may have predisposed the dislocation or can influence the course of treatment. Rotator cuff, surface area of contact and capsulolabral complex may be damaged by the trauma but could also be congenitally disposed to dislocation or have damaged traumatic forces over time. It is appreciated that asymptomatic individuals greater than 60 years old had 28 % incidence of full thickness rotator cuff tears, 26 % partial thickness tears, and this increases to 80 % in the eighth decade of life [44].

Therefore, treatment options should be dependent on patient’s goals, etiology and depth of the tear. Wolf et al., states, considerable thought should be given to differentiating between articular and bursal-sided tears and nonsurgical treatment with rehabilitation is successful in most patients and may be a viable option for management [45].

In the initial phase, clinical diagnosis of a rotator cuff tear may be difficult secondary to pain, guarding, and previous shoulder pathology [46]. Imaging may be obtained to identify the severity of intrinsic variables after injury.

The diagnostic performance of MRI and ultrasonography (US) may be similar for detection of any rotator cuff tears. However, the sensitivity of US may be much lower than that of MRI for detecting partial thickness tears [56]. Although radiographs are important screening tools, the definitive imaging assessment is obtained with cross-sectional imaging. CT is the first-line imaging modality for the evaluation of glenoid bone loss and Hill-Sachs lesions. MRI can also be used to identify Hill-Sachs lesions, glenoid bone loss and for the evaluation of the soft- tissue injuries [57]. Diagnostic arthroscopy is useful to look at the subtleties of internal lesions such as deep surface cuff or bicipital lesions.

Extreme sport athletes may have a lower threshold for surgical reconstruction than the general population due to patient goals, expectations, and participation in sports with forced overhead activities, which may increase the risk of recurrence of shoulder dislocation [58, 59]. If there are structural damages to the capsulolabral complex (eg. Bankart or SLAP lesion) and the patient is returning extreme sport, then surgery is often recommended to avoid recurrence [60, 61]. However, literature within overhead throwing athletes is most profound and, although hard to generalize to the extreme sports population, it is to be noted that anywhere between 40 and 50 % of throwing athletes will have a recurrent dislocation [62, 63]. This evidence suggests discussion with the patient’s surgeon should be comprehensive and consider all avenues of treatment options. It is also important to be clear about expectations with the patient as return to overhead activity is complex with a myriad of intrinsic and extrinsic factors.

Details regarding various surgical options are outside the scope of this chapter but common surgeries seen in clinic include arthroscopic surgical rotator cuff repairs, labral repairs, and anterior shoulder stabilization (shoulder stabilization described with suture anchors, proper suture placement, capsulorrhaphy, and occasional rotator interval plication) [31, 64, 65]. Participation in extreme sports is not contraindicated for the above-described surgeries after proper healing times and rehabilitation is implanted within the discretion of the therapist and surgeon. After arthroscopic shoulder stabilization no statistical difference was found in recurrence rates comparing collision athletes with non-collision sports participants [66].

34.3.2 Rehabilitation

Rehabilitation after ASD is paramount to avoiding future dislocation and allowing the athlete to return to their sport.

Surgical rehabilitation following a traumatic anterior dislocation of the shoulder may allow return to sporting activity after an average period of 4–6 months [61].

This is dependent on injury type and/or surgical procedure performed [31]. It is important to note that all rehabilitation programs should be independently developed to the patient with special consideration of intrinsic (age, gender, surgery performed, injury) and extrinsic factors (patient goals, patient expectations, participation, previous injury).

During the initial period of rehabilitation, goals of the therapist and patient are to manage pain, swelling, stiffness, weakness, loss of proprioception and maladaptive postures that may impede proper healing of tissue. As expected, icing, taping and patient education are vital in primary phases of recovery. If the patient is non-operative, special considerations at this phase include bracing. Bracing with sling use may be utilized per patient comfort as evidence is inconclusive on duration and position although bracing in external rotation may be beneficial for the younger athlete [67].

Postural taping, although limited in its research, can provide sensory feedback as it is important that the patient becomes proficient in proper positioning of the scapula during elevation, lowering, retraction and protraction along with dissociation of the glenohumeral joint [61]. This may also play a role in pain modulation for the guarded patient.

The following intermediate phase permits recovery of a full range of movement within pain free planes. At first this occurs passively: keeping the elbow bent at a 90° angle, the therapist guides the limb through a series of shoulder movements, applying a downward caudal translation through the elbow to increase congruency of the glenohumeral joint [61]. Protection of vulnerable positions of the glenohumeral joint may be implied at this phase to allow proper healing of injured structures. These must be performed as far as the pain permits, and should in any case be avoided when there is the risk of instability. Again, special non-operative considerations here would be arthrokinematic mobilization of the glenohmeral joint to allow freedom of movement and assist with pain modulation as well as improvement in range of motion. Although this may also be utilized post-operatively, consideration of surgeon preferences must be noted.

Arthrokinematics of the glenohumeral joint are important to consider but not well defined. In terms of manual therapy, if the therapist is attempting to improve external rotation pain free, Johnson et al. demonstrated that a posterior glide of the humeral head was more effective to increase external rotation than anterior glides, thus challenging the idea that external rotation would be limited by the anterior capsule [68]. Regardless, testing and re-testing impairment of focus after use of manual therapy would prove important to the patient in physiotherapist's office.

With the patient lying supine and the arm supported, active glenohumeral rotation at 90° abduction can be initiated, seeking to maintain good control of the scapula and glenohumeral joint [61]. The patient can gain proprioceptive feedback by placing the hand of the unaffected side on the front of the shoulder. The addition of a lightweight bar encourages activation of the biceps, another important glenohumeral stabilizer.

Early submaximal isometric exercises for the rotator cuff may be proposed if pain permits in all planes of movement [61]. It is noted, to isolate activation of the subscapularis muscle from that of the pectoralis major, one technique is for the patient to place their hand on a cushion positioned on the belly, with the elbow out to the side. Maintaining this position, the patient should push on the pillow (5–10 s submaximal contraction), avoiding contraction of the pectoralis major secondary to its role in possible poor posturing [69]. This technique is extremely useful because the subscapularis muscle plays a role in glenohumeral stability [70].

The rotator cuff acts as servomechanism crucial to joint stability: it must be activated with closed chain exercises to enhance recovery and stimulate muscular co-activation and proprioception. During this phase, rotator cuff exercises must be performed with the aid of a fixed support to encourage co-activation of the muscles and stability of the scapula, limiting the shear forces across the shoulder joint as much as possible [71–74]. This is of obvious consideration of the therapist secondary to mechanism of injury although not all patients can tolerate this

Fig. 34.3 Demonstration of external rotation strengthening

approach, patient specific modifications are appropriately made.

Progression of rotator cuff exercises can then be performed by focusing on repetitions rather than increasing load: the ideal workload is 10–40 % of maximal voluntary isometric contraction [61]. Prone or side lying positions inhibit the effect of the pectoralis major and latissimus dorsi: inappropriate compensation by using these muscles may increase the risk of developing recurrent instability. At this stage, the introduction of closed chain exercises on unstable surfaces such as Swiss ball may enhance neuromuscular control at a reflex level and improve proprioception [75].

The third stage is functional rehabilitation, which includes strength, endurance and dynamic stabilization (Figs. 34.3, 34.4, and 34.5). Plyometric exercises, for example medicine ball throws and dynamic movement patterns that replicate preferred sport can be considered [61]. Lower extremity strengthening, included with upper extremity management, can be utilized for movement retraining; such as single leg squats with dynamic upper extremity control.

Fig. 34.4 Flexion strengthening

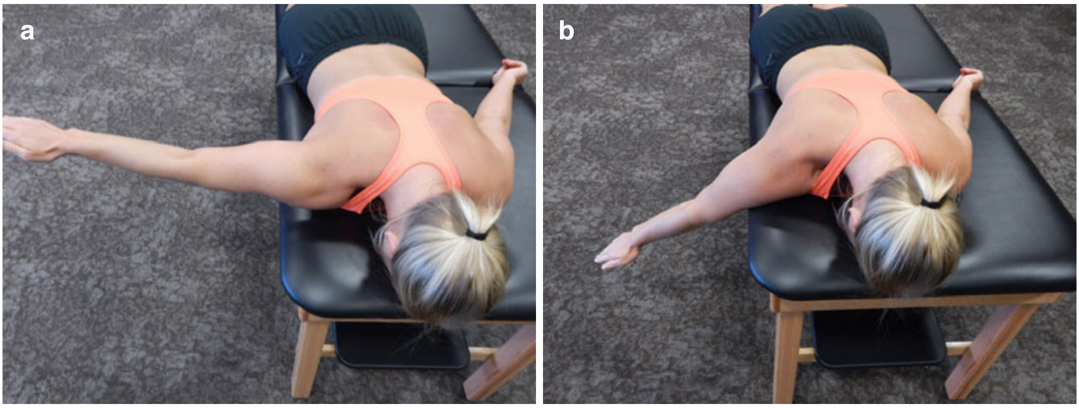

Fig. 34.5 (**a**, **b**) Scapular strengthening in prone position

During this phase, it is important to focus on patterns of movement biased toward functional tasks specific to the sport practiced. This not only improves control and strength but as a special consideration of extreme sport athletes, speed and confidence need to be ingrained as well. The element of speed should not be introduced into rehabilitation exercises until the strength of the shoulder during elevation and rotation is at least 80 % as compared to the unaffected side [76]. Furthermore, they should not be performed unless the pain is minimal or absent.

If confidence is lacking, there is the risk of compensating with inappropriate movements, increasing the risk of re-injury and instability. Return to sporting activity should be undertaken gradually, in favorable environmental conditions, temporarily avoiding demanding and risky activities such as rough water in water sports, or wet snow slopes in winter sports. It is also useful to determine if the athlete's specific sporting technique can be improved to prevent recurring symptoms and injury by encouraging the use of the entire kinetic chain in athletic technique, making inappropriate muscle activation at the shoulder girdle less likely.

Overall, shoulder dislocations are common in the extreme sport athlete but with proper treatment and rehabilitation, athletes may return to their sport safely.

34.4 Acute Low Back Pain

Acute low back pain (LBP) is defined as 6–12 weeks of pain between costal angles and gluteal folds that may or may not radiate into lower extremities [77]. Non-specific LBP is defined as LBP not attributed to identifiable, known specific pathology (e.g., tumor, infection, ankylosing spondylitis, osteoporosis, fracture, cauda equina syndrome) [77]. Most patients resolve symptoms however, 31 % of patients with LBP will not fully recover in 6 months [77].

LBP is a commonly managed condition in most care providers' offices, as two thirds of adults will be affected in their lifetime [77]. For scope of this chapter and following suit of previous two conditions, acute LBP will be focused on from diagnosis to best evidence based management. It is appreciated that chronic LBP differs in management and will be outside the scope of this chapter.

Prevalence rates have been speculated to be higher in endurance athletes, and although no large studies have been performed for LBP in extreme sport athletes, studies have been performed in skiers and rowers, which can be generalized with understanding of its limitation. Endurance athletes in skiing and snowboarding have no increased incidence of LBP than the general population; although a slight increase in prevalence of LBP in rowing type sports secondary to obvious environmental requirements are noted [78, 79]. Incidence rates are also prevalent in water sports, including: sailing, and wind surfing, where 79 % of professional wind surfers report to having LBP [80–83].

34.4.1 Diagnosis and Management

The acute LBP present in most patients is nonspecific in origin [84, 85]. Thorough examination should be performed to rule out sinister pathology. Red flags should be systematically evaluated in this population, especially after contact injury; these include: assessing changes in bladder function, major or progressive motor or sensory deficit, saddle anesthesia, history of cancer or suspected spinal infection. Once the first round of screening is exhausted, the medical provider should continue to evaluate for renal, cardiac, or other non-musculoskeletal disorder until the care provider is confident that the patient is presenting with solely a musculoskeletal condition [84].

After considering appropriate placement of patient in physioterapist'soffice, ruling out traumatic injury to the spine is crucial. Although possibly less severe than cervical spine traumatic injuries, secondary to imperative nature of cervical structures, lumbar spine injuries are still important to assess concerning bony pathology for the athlete. Spondylolysis is most common in clinic and is defined as a defect in the pars interarticularis of the vertebral arch. Eighty-five to 95 % of the cases affect L5 and 5–10 % affect L4, with more proximal vertebrae being affected much less often [86]. This can be a relatively common finding in radiologic studies of lumbar spine and it may be completely asymptomatic or can be pain-provoking structures. Painful spondylolysis is particularly a problem in adolescent athletes. Spondylolisthesis may be associated with spondylolysis (about 25 % of occurrences), which is defined by the forward displacement of the vertebral body on the subjacent one [87].

Table 34.2 Witse's classification of spondylolysis [86]

Type		Pathogenesis
I. Dysplastic		Congenital abnormality
II. Isthmic	Lytic	Fatigue fracture
	Elongated	Elongated as a result of overuse but not interrupted pars
	Acute	Acute fracture
III. Degenerative		Remodeling of the articular processes
IV. Traumatic		Acute fracture in vertebral arch other than the pars
V. Pathological		Osteolysis related to generalized or focal bone disease

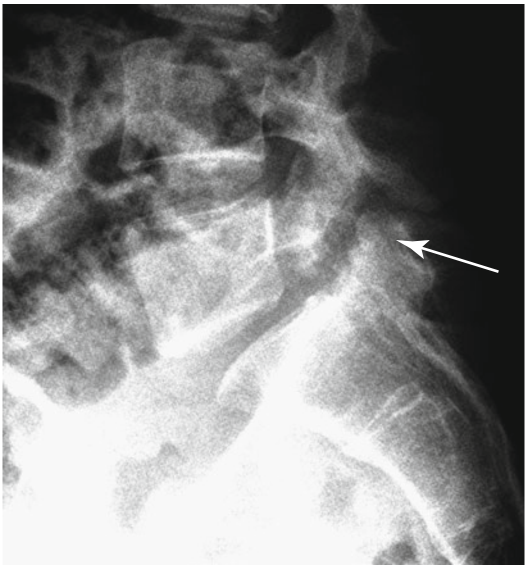

Fig. 34.6 Radiologic demonstration of spondylolysis (*arrow*) associated with low-grade spondylolisthesis, affecting a 36-year-old female athlete practicing different extreme sports, including windsurfing and diving

Symptomatic spondylolysis usually presents with focal LBP, occasionally with radiation into the buttock or proximal lower extremities. The onset of the symptoms may be gradual with an acute worsening after a particular event or may suddenly occur after an acute injury depending on the pathogenesis [87–89].

Even if pathogenesis can recognize several mechanisms (Table 34.2), in extreme sports types II, III and IV are of specific interest (Fig. 34.6). Pars interarticularis elongation caused by overuse (type II) is common among sailors, windsurfers, divers, weight lifters and rowers [82, 87, 90]. In addition to this, however, a single traumatic event may precipitate a stress fracture that has been developing secondary to faulty movement behaviors, or may cause the initial microfracture in the pars intertarticularis.

Other area of common focus is disc pathology. Adolescents in elite sports with severe lumbar anterior end plate lesions may have an increased risk for LBP. However, in the acute patient, this may lend little information to treatment in conservative management. Often, asymptomatic patients demonstrate disc pathology indicating possible lack of use for clinical decision-making.

In asymptotic individuals disc degeneration is 37 and 96 %; disc bulges 30 and 84 % of 20 year olds and 80 year olds respectively [91].

Therefore, severe changes may be implied to diagnosis but does not under-credit proper valuation and treatment of the lumbar spine for acute pain [92, 93]. Finally, there is no evidence on the association between degenerative signs at the acute stage and the transition to chronic symptoms [85].

With above noted “normal” changes in lumbar spine, imaging use is often discussed within health care professionals in management of acute LBP. A recent review of the diagnostic imaging literature concluded that imaging does not improve treatment of LBP [85]. Therefore, American and European guidelines do not recommend imaging unless severe pathology is suspected for acute LBP [77, 85].

If the patient is deemed appropriate for rehabilitation management for their acute LBP, discussion changes from pathology to progression of training, correcting faulty technique and use of manual techniques for pain management.

34.4.2 Rehabilitation

As discussed above, a pathology-based approach to diagnosis for LBP has proven difficult because of the inability to identify a structural pathology in the vast majority of patients with LBP [94]. As previously stated, numerous items may require further evaluation in chronic LBP patients that may differ in treatment methods to that of an extreme sport athlete with acute LBP. In lieu of these points, a classification system may be useful for organization of management of patients with LBP. Many classification systems have been presented, some based on pathology, and some based in rehabilitation methods.

Patho-anatomical models are challenging for management in the physiotherapists’ office as pathology can correlate with <20 % of reasons for LBP [94]. Therefore, Fritz et al., proposes a method to gather data and subgroup this overall heterogeneous group to guide therapists in their decision making processes. The four categories include: manipulation, stabilization, specific exercise and traction [95–97]. The remainder of this section will evaluate literature within the first three categories as these are used primarily for the extreme sports athlete with acute LBP and cross-examine them with international guidelines.

European and United States guidelines for acute non-specific LBP appear similar including: education to remain active, medication if necessary for pain management, and spinal manipulation [77, 92]. It is generally accepted that bed rest is not recommended to patients secondary to increased weakness and stiffness along with fear avoidance behaviors [98].

Although medication management and education may be enough to treat many with acute LBP,, extreme sport athletes may have higher demands of return to athletics and may require specific guidance to their sport and/or manual techniques to hopefully shorten duration of episode [77].

Often considered in early phases of non-specific acute LBP is spinal manipulation. In most guidelines, spinal manipulation is considered to be a therapeutic option in first weeks of LBP. The UK, US, New Zealand and Danish guidelines state that spinal manipulation can be a useful tool to modulate pain [98–101]. Australian, Israeli and Dutch guidelines do not recommend manipulation in acute LBP [102–104]. Challenges in developing heterogeneous population samples in this group provide difficulty in clear delineated guidelines for management. Therefore, an often-referenced study by Flynn et al., and subse-

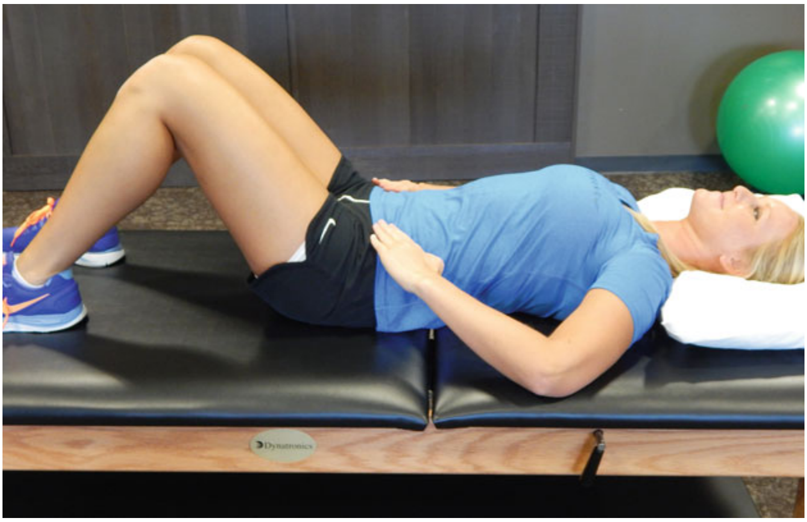

Fig. 34.7 Transverse abdominus strengthening

quently validated by Childs et al., demonstrates use of prediction rule criteria to identify responders to this treatment [105–107]. Patients who benefit most from spinal manipulation presented with four of the following five criteria: symptom duration less than 16 days, symptoms not distal to the knee, score of 19 or less on fear avoidance measure (work subscale of the Fear-Avoidance Beliefs Questionnaire), one hip with more than 35° of internal rotation and one hypomobile lumbar segment [105]. Patients with five of these factors demonstrated a 50 % improvement in disability within 1 week of onset of care [98, 107].

Subsequent category of specific exercise is commonly referred to as McKenzie method, directional preference, or mechanical diagnosis and therapy. Referencing back to Fritz et al., this is considered most classically used for patients with symptoms past the knee [97]. United States and Danish recommendations state that McKenzie method and spine stabilization exercises to decrease repeat episodes of LBP may be useful in management of acute LBP [77, 85].

Again, recommendations for stabilization exercises are not clearly stated across country-to-country guidelines. Common to the theme of manipulation, this may be secondary to heterogeneous population samples concerning LBP. Per European guidelines, back-specific exercises (e.g., strengthening, flexion, extension, stretching) are considered not useful during the first weeks of an episode. Yet again, variability of guidelines lends little guideline to rehabilitation programs and therapist choices of interventions therefore, best available evidence should be considered when managing the extreme sport athlete with acute LBP.

Even with variability within literature and guidelines, management of acute LBP in extreme sport athletes seems to state importance of use of manual techniques in addition to progression to any pain free strengthening program with advance to return to sport specific strengthening. Although generally recommended, strengthening is not strongly supported within literature for acute LBP; understanding of this population's demands is imperative and varies from general population. Focus should be placed on re-training rectus abdominus, transversusabdominus, internal oblique, and multifidus for stability [108–113] (Figs. 34.7 and 34.8). Progression of these exercises begins in supine, transitioning to quadruped, then in closed kinetic chain positioning and finally transitioned into dynamic environments often encountered by the athlete.

The athlete should demonstrate adequate positioning of the spine to reduce lumbar loading forces seen in their sport to reduce pain and future episodes and also to increase patient's comfort level with returning to activity. For example, transverse abdominus is retrained supine with

Fig. 34.8 Bridging with marching

drawing in maneuver, progressed to quadruped control, then into squat form retraining, and finally sport specific retraining to ensure athlete maintains control of lumbar spine in static and dynamic environments. Once the athlete demonstrates spine control, confidence and understanding of back management patient is discharged to independent program.

Overall, management of the athlete can derive along classification systems with a dose of expert opinion. Use of manual techniques to reduce acute pain are indicated in non-specific LBP, use of directional preference to reduce initial pain and/or centralize symptoms, progression of strengthening from static to dynamic environments are all commonly used, and evidence based techniques are used internationally for this population.

34.5 Anterior Cruciate Ligament Rupture

Anterior cruciate ligament (ACL) rupture is a common injury in extreme sport athletes with upwards of 250,000 ACL injuries per year in the United States alone; the numbers for international incidence rates are limited. Upwards of 50 % of these injuries, demonstrate concomitant meniscal pathology increasing complexity of recovery [114].

Sports that frequently present this injury are most extreme sports described in this book including skiing and snowboarding, which result from variable traumatic mechanisms including extrinsic and intrinsic patient factors (for further detail see chapter: “Alpine skiing and snowboarding: current trends and future directions”). In wakeboarding and kitesurfing, ACL rupture may be the consequence of an imbalanced landing from a jump. In surfing and kitesurfing, the mechanism often involves femoral external rotation and tibial internal rotation which creates valgus knee loading, as a consequence of this rotational force the ACL is stressed and subsequently damaged to varying degrees [115]. Many intrinsic variables contribute to ACL tears, although rehabilitation will focus efforts primarily on extrinsic factors. The two largest areas of focus that lead to ACL tears are decreased internal femoral rotation [116] and internal tibial torque combined with a knee valgus moment as described as the worst-case ACL loading condition [114].

Conservative management can be suitable for extreme sport athletes, especially since knee stability can be improved not only by surgery, but also by rehabilitation. Non-surgical treatment of this condition may be a strong option in the absence of concomitant meniscal or ligamentous injury when function is well conserved in performance tests such as the "hopping test" or when "giving way" (instability) is minimal or absent [117]. Whether the chosen approach is surgical or conservative, rehabilitation plays a key role in a rapid and risk-free return to previous level of sporting activity.

34.5.1 Rehabilitatiosn

Rehabilitation of an ACL reconstruction (ACLR) can be split into four general phases. The rehabilitation program changes if meniscal repair is involved but for purpose of this chapter, a standard ACLR (grouped autografts and allografts) will be discussed with current evidence and treatment of non-operative ACL tears will be touched on in conjunction to these protocols.

The first 4 weeks after surgery represent the initial and acute phase of post-operative rehabilitation of an ACL reconstruction. Strict guidelines are given to the patient at this time as lack of graft incorporation is noted in the first 2–4 weeks. Then at 12 weeks the graft begins to return to normative values of the ACL and finally resembles the appearance of a native ACL 6–12 months after surgery [118]. This biology of healing should guide therapists' consideration about intensity and stress to the knee while attempting to achieve rehabilitation goals.

For the post-operative patient, surgical wound care is critical in the early stages along with reduction of effusion and pain, including ice and elevation. Initial phase of rehabilitation involves gentle knee stretches for restoring flexibility to achieve and maintain near or full range of motion (ROM) both in knee flexion and extension. Early ROM recovery reduces the risk of arthrofibrosis, therefore, to target the achievement of a full ROM in the first 2–3 weeks is beneficial [119]. Along with range of motion, straight-leg raises to facilitate early quadriceps reactivation and hip strength are standard approach. Also, in this phase, patellar mobilization and eccentric exercises can be considered for the athlete.

These exercise goals are to prevent the muscle fiber atrophy that is a natural consequence of knee surgery. Numerous studies have demonstrated that electrical stimulation when combined with voluntary muscle contraction can assist to prevent muscular atrophy in the early phase of rehabilitation [120–122]. This may assist with commonly observed arthrogenic muscle inhibition after ACLR, which inhibits volitional contraction of the quadriceps muscle [123].

The role of postoperative brace use in ACL rehabilitation is controversial; review of the literature demonstrates that the use of a brace is not required [120]. However, it may be useful for the first one to two weeks in patients who find it difficult to regain their confidence while they improve quadriceps contraction and manage swelling. Gait training should challenge the patient but also protect the repair. Proprioceptive training to begin focus on walking without crutches and a progression to achieve normal weight bearing gait are a focus in this phase.

Another consideration is incorporating exercises to improve the athlete's lumbopelvic stability, which can include targeting transverse abdominus, gluteus medius and maximus along with abdominal obliques to reduce effects of deconditioning and possible predisposing factors that led to injury initially [124].

As the patient's goal is to return to high-level activities, maintenance of their cardiovascular endurance should not be forgotten with use of arm ergometer, aquatic walking and biking dependent on phases of healing. It has also been shown that a combination of classical rehabilitative conditioning combined with balance, speed court trainings and training on the alpine ski simulator allows alpine ski training to begin two months earlier than use of conventional rehabilitation programs alone [125]. This would add functional return to sport in early phases of rehabilitation programs.

The second phase of rehabilitation is between the first and fourth month post surgery. During this time, the therapist should challenge fatigue, strength and stability with sport specific requirements while respecting healing considerations as the athlete progresses along the course of reha-

Fig. 34.9 Single-leg proprioception with reach-outs

Fig. 34.10 Step-up strengthening

bilitation. This progresses in intensity as the patient transitions from the first to second phase.

Lumbopelvic stability training exercises are progressed, while those for flexibility and straight plane strengthening (with the addition of isokinetic hamstring exercises) are reduced. Proprioceptive neuromuscular facilitation exercises for quadriceps and hamstrings are useful, since the coordinated co-activation of the hamstrings and quadriceps may play a role in mitigating primary injury risk by reducing ligament strain [126] while promoting ideal landing mechanics [127] (Fig. 34.11). During training sessions to increase muscle strength and mass, closed chain exercises are likely to give less laxity and fewer patellofemoral problems than open-chain exercises and may be more functional to the athlete [128].

To evaluate if the combined hip and quadriceps femoris strength is adequate to more intense primarily sagittal plane exercises, it may be useful to implement a functional test which is outside the scope of this chapter but can include such tests as the lateral step-up or step down and star excursion testing [124]. Of important note, fatigue based functional testing is imperative to consider for patients to maintain adequate return to sport protection to reduce ACL compromise. As there is no universally excepted functional testing, sport demands, healing timeframes, and stressing lower extremity control within functional environments to the athlete should be appraised.

Before proceeding to greater impact loads such as jumping, hopping and bounding, it is also necessary to confirm appropriate frontal plane hip and knee position during low impact exercises such as step-ups, lunges, and/or single leg squats (Figs. 34.9 and 34.10). Ideas for challenging an athlete may include but not be limited to: a metronome used to guide timing, a weighted vest to increase loads, an adjustable step or BOSU ball to increase the motor control change, environmental changes including decreasing visual dependence to challenge the patient in variable conditions that may be required for an extreme athlete. Dependent on swelling, pain and healing

Fig. 34.11 Forward lunges

stages, continued progression of each exercise is determined. For example, as lunges become simple adding dynamic surfaces, upper trunk rotations, or ball tosses challenge a variety of systems. Swimming, indoor bicycling and deep water running may also be introduced in this phase.

The third phase at the 4–6 month mark is the sport specific phase. The goals in this phase are pain free landing and hopping from double to single leg and pain and effusion free jogging and running.

At this time, the attention is focused on advanced neuromuscular and functional strengthening exercises: this includes agility, plyometrics, and sport specific exercises that challenge the patient to ensure safe return to sport.

Before proceeding to greater impact loads, again, functional tests that indicate neuromuscular control, strength, power and most importantly knee stability should be performed; these tests include jumping, hopping and bounding, including one-leg hopping and jumping tests. During this phase, sport specific lateral knee movements should be included in progressively more challenging exercises.

The fourth and final phase in the rehabilitation of ACL rupture is return to sporting activity and begins around 6 months after surgery. Prior to entering this phase, it is important that the athlete achieve a number of goals. They should not experience any pain or swelling during or after training. Quadriceps and hamstring strength should be at least 85 % of the unaffected leg [120]. They should have achieved flawless running technique to maintain adequate results of functional tests and reach sport specific aerobic/anaerobic measures.

At the time of return to sport, athletes post-ACL reconstruction with nearly symmetrical quadriceps femoris muscle strength demonstrate landing patterns similar to uninjured individuals. While individuals with less strength in this muscle group have altered landing patterns, which may lead to re-injury of the ACL or to new injuries [129].

The last, but crucial, consideration is psychosocial contributors. The need to regain self-confidence and overcome kinesiophobia represents another fundamental aspect of return to sport. Kinesiophobia is defined as the irrational or debilitating movement of physical activity, resulting in a feeling of vulnerability to painful injury or re-injury, and may have a significant impact on extreme sport athletes [130]. Hesitancy in the practice of these sports may increase reaction times and make actions less decisive, leading to re-injury or injuries that are more serious.

It is necessary to work on this aspect from the very beginning of the rehabilitative process; a reduced post-operative acute care period and early introduction of functional exercises help to increase confidence and self-efficacy [124]. It is of fundamental importance to substitute the "patient role" with the "athlete role" as soon as possible. Rehabilitative exercises, due to the simulation of athletic movements and their subcomponents, involvement of the coach or coaching staff and recreation of the experience of sporting and competition are all helpful components to prepare the athletic mentality.

Increased self-efficacy and confidence and decreased kinesiophobia suggest a greater patient willingness to use the involved lower extremity [120, 124]. Overall, this concept demonstrates the importance of evaluating patients in all areas that may limit return to sport participation.

References

1. McCrory P, Meeuwisse WH, Aubry M, Cantu RC, Dvořák J, Echemendia RJ, Engebretsen L, Johnston K, Kutcher JS, Raftery M, Sills A, Benson BW, Davis GA, Ellenbogen R, Guskiewicz KM, Herring SA, Iverson GL, Jordan BD, Kissick J, McCrea M, McIntosh AS, Maddocks D, Makdissi M, Purcell L, Putukian M, Schneider K, Tator CH, Turner M. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport, Zurich 2012. Br J Sports Med. 2013;47(5):250–8.
2. Harmon KG, Drezner JA, Gammons M, et al. American Medical Society for Sports Medicine position statement: concussion in sport. J Sports Med. 2013;47:15–26.
3. Tator CH. Let's standardize the definition of concussion and get reliable incidence. Can J Neurol Sci. 2009;36:405–6.
4. Soreide K, Ellingsen CL, Knutson V. How dangerous is BASE jumping? An analysis of adverse events in 20,850 jumps from Kjerag Massif, Norway. J Trauma. 2007;62:1113–7.
5. Heggie TW, Caine JW, editors. Epidemiology of injury in adventure and extreme sports. Basel: Karger; 2012.
6. Bridges EJ, Rouah F, Johnston KM. Snowblading injuries in eastern Canada. Br J Sports Med. 2003; 37:511–5.
7. Pikora TJ, Braham R, Mills C. The epidemiology of injury among surfers, kite surfers and personal watercraft riders: wind and waves. In: Heggie TW, Caine DJ, editors. Epidemiology of injury in adventure and extreme sports, Med Sport Sci, vol. 58. Basel: Karger; 2012. p. 80–97.
8. Jablecki CK, Garner SA. Neurological complications of windsurfing. Semin Neurol. 2000;29(2):219–23.
9. Sulheim S, Holme I, Ekeland A, et al. Helmet use and risk of head injuries in alpine skiers and snowboarders. JAMA. 2006;295:919–24.
10. Davidson J. Epidemiology and outcome of bicycle injuries presenting to an emergency department in the United Kingdom. Eur J Emerg Med. 2005;12:24–9.
11. Harmon KG, Drezner JA, Gammons M, Guskiewicz KM, Halstead M, Herring SA, Kutcher JS, Pana A, Putukian M, Roberts WO. American medical society for sports medicine position statement: concussion in sport. Br J Sports Med. 2013;47:15–26. doi:10.1136/bjsports-2012-091941.
12. Fothergill DM, Hedges D, Morrison JB. Effect of CO2 and N2 partial pressures on cognitive and psychomotor performance. Undersea Biomed Res. 1991;18:1–19.
13. Regard M, Oelz O, Brugger P, et al. Persistent cognitive impairment in climbers after repeated exposure to extreme altitude. Neurology. 1989;39:210–3.
14. Broglio SP, Cantu RC, Gioia GA, Guskiewicz KM, Kutcher J, Palm M, Valovich McLeod TC. National athletic trainers' association position statement: management of sport concussion. J Athl Train. 2014;49(2):245–65. doi:10.4085/1062-6050-49.1.07.
15. Piland SG, Motl RW, Ferrara MS, Peterson CL. Evidence for the factorial and construct validity of a self-report concussion symptoms scale. J Athl Train. 2003;38(2):104–12.
16. Randolph C, Millis S, Barr WB, et al. Concussion symptom inventory: an empirically derived scale for monitoring resolution of symptoms following sport-related concussion. Arch Clin Neuropsychol. 2009;24(3):219–29.
17. McCrea M, Barr WB, Guskiewicz K, et al. Standard regression-based methods for measuring recovery after sport-related concussion. J Int Neuropsychol Soc. 2005;11(1):58–69.
18. McCrea M. Standardized mental status testing on the sideline after sport-related concussion. J Athl Train. 2001;36(3):274–9.
19. McCrea M. Standardized mental status assessment of sports concussion. Clin J Sport Med. 2001;11(3): 176–81.
20. Khurana VG, Kaye AH. An overview of concussion in sport. J Clin Neurosci. 2012;19(1):1–11. J Athl Train. 2013;48(4):554–75. doi:10.4085/1062-6050-48.4.05.
21. McCrory P, Davis G, Makdissi M. Second impact syndrome or cerebral swelling after sporting head injury. Curr Sports Med Rep. 2012;11(1):21–3. doi:10.1249/JSR.0b013e3182423bfd.
22. List M, Nolz Z, Nord W, Huntington M. Return-to-play: a primary care physician's guide to management. S D Med. 2015;68(3):121–3, 125.
23. Mucha A, Collins M, Elbin R, Furman J, Troutman-Enseki C, DeWolf R, Marchetti G, Kontos A. A brief vestibular/ocular motor screening (VOMS) assess-

ment to evaluate concussions. Am J Sports Med. 2014;42(10):2479–86.

24. Schneider K, Meeuwisse W, Nettel-Aguirre A, Barlow K, Boyd L, Kang J, Emery C. Cervicovestibular rehabilitation in sport related concussion: a randomised controlled trial. Br J Sports Med. 2014;48:1294–8.
25. Dyson R, Buchanon M, Hale T. Incidence of sports injuries in elite competitive and recreational windsurfers. Br J Sports Med. 2006;40:346–50.
26. Rosembaum DA, Simmons B. Windsurfing. In: Mei Dan O, Carmont MR, editors. Adventure and extreme sports injuries. London: Springer; 2013. p. 189–202.
27. Nathanson AT, Reinart SE. Windsurfing injuries: results of a paper- and internet-based survey. Wilderness Environ Med. 1999;10(4):218–25.
28. Sutherland A, Holmes J, Myers S. Differing injury patterns in snowboarding and alpine skiing. Injury. 1996;27:423–5.
29. Ogawa H, Sumi H, Sumi Y, Shimizu K. Glenohumeral dislocations in snowboarding and skiing. Injury. 2011;42(11):1241–7.
30. Nathanson A, Bird S, Dao L, Tam Sing K. Competitive surfing injuries. Am J Sports Med. 2007;35:113–7.
31. Kim SH, Ha KI, Jung MW, et al. Accelerated rehabilitation after arthroscopic Bankart repair for selected cases : a prospective randomized clinical study. Arthroscopy. 2003;19:722–31.
32. Longo UG, Huijsmans PE, Maffulli N, Denaro V, De Beer JF. Video analysis of the mechanisms of shoulder dislocation in four elite rugby players. J Orthop Sci. 2011;16(4):389–97. doi:10.1007/s00776-011-0087-6. Epub 2011 May 13.
33. McCall D, Safran MR. Injuries about the shoulder in skiing and snowboarding. Br J Sports Med. 2009;43(13):987–92. doi:10.1136/bjsm.2009.068767.
34. Kocher MS, Feagin Jr JA. Shoulder injuries during alpine skiing. Am J Sports Med. 1996;24(5):665–9.
35. Lundgren L, Brorsson S, Hilliges M, Osvalder A. Sport performance and perceived musculoskeletal stress, pain and discomfort in kitesurfing. Int J Perform Anal Sport. 2011;11(1):142–58.
36. Kristen K, Syré S, Humenberger M. Kitesurfen – sportmedizinische Aspekte, Risikofaktoren und Verletzungen. OUP. 2014;6:306–11. doi:10.3238/oup.2014.0306-0311.
37. Westman A. Skydiving. In: Mei-Dan O, Carmont MR, editors. Adventure and extreme sports injuries. London: Springer; 2013. p. 84.
38. Burrell C, Burrell R. Injuries in whitewater paddling. Phys Sportsmed. 1982;10:119–24.
39. Schoen RG, Stano MJ. Year 2000 whitewater injury survey. Wilderness Environ Med. 2002;3(2):119–24.
40. Krupnick JE, Cox RD, Summers RL. Injuries sustained during competitive white-water paddling: a survey of athletes in the 1996 Olympic trials. Wilderness Environ Med. 1998;9(1):14–8.
41. Fiore DC, Houston JD. Injuries in whitewater kayaking. Br J Sports Med. 2001;35(4):235–41.
42. Edwards A. Injuries in kayaking. Sport Health. 1993;11:8.
43. Wassinger CA, Myers JB, Sell TC, Oyama S, Rubenstein EN, Lephart SM. Scapulohumeral kinematic assessment of the forward kayak stroke in experienced whitewater kayakers. Sports Biomech. 2011;10(2):98–109.
44. Milgrom C, Schaffler M, Gilbert S, van Holsbeeck M. Rotator-cuff changes in asymptomatic adults: the effect of age, hand dominance and gender. J Bone Joint Surg Br. 1995;77:296–8.
45. Wolff AB, Sethi P, Sutton KM, Covey AS, Magit DP, Medvecky M. Partial-thickness rotator cuff tears. J Am Acad Orthop Surg. 2006;14:715–25.
46. Smith GCS, Chesser TJS, Packham IN, Crowther MAA. First time traumatic anterior shoulder dislocation: a review of current management. Injury. 2013;44(4):406–8.
47. Neviaser TJ. The anterior labroligamentous periosteal sleeve avulsion lesion: a cause of anterior instability of the shoulder. Arthroscopy. 1993;9(1):17–21.
48. Wolf EM, Cheng JC, Dickson K. Humeral avulsion of the glenohumeral ligaments as a cause of anterior shoulder instability. Arthroscopy. 1995;11:600–7.
49. Baker CL, Uribe JW, Whitman C. Arthroscopic evaluation of acute initial anterior shoulder dislocations. Am J Sports Med. 1990;18(1):25–8.
50. Taylor DC, Arciero RA. Pathologic changes associated with shoulder dislocations. Arthroscopic and physical examination findings in first-time, traumatic anterior dislocations. Am J Sports Med. 1997;25(3):306–11.
51. Wintzell G, Haglund-Akerlind Y, Ekelund A, Sandstrom B, Hovelius L, Larsson S. Arthroscopic lavage reduced the recurrence rate following primary anterior shoulder dislocation. A randomised multicentre study with 1-year follow-up. Knee Surg Sports Traumatol Arthrosc. 1999;7(3):192–6.
52. Larrain MV, Montenegro HJ, Mauas DM, Collazo CC, Pavon F. Arthroscopic management of traumatic anterior shoulder instability in collision athletes: analysis of 204 cases with a 4- to 9-year follow-up and results with the suture anchor technique. Arthroscopy. 2006;22(12):1283–9.
53. Robinson CM, Jenkins PJ, White TO, Ker A, Will E. Primary arthroscopic stabilization for a first-time anterior dislocation of the shoulder. A randomized, double-blind trial. J Bone Joint Surg Am. 2008;90(4):708–21.
54. Lin CL, Su FC, Chang CH, Hong CK, Jou IM, Lin CJ, Su WR. Effect of shoulder abduction on the fixation of humeral greater tuberosity fractures: a biomechanical study for three types of fixation constructs. J Shoulder Elbow Surg. 2015;24(4):547–54.
55. Zuckerman JD, Koval KJ. Atlas of orthopaedic surgery: a multimedia reference. Philadelphia: Lippincott Williams & Wilkins; 2004. p. 62.
56. Lenza M, Buchbinder R, Takwoingi Y, Johnston RV, Hanchard NC, Faloppa F. Magnetic resonance imaging, magnetic resonance arthrography and ultraso-

nography for assessing rotator cuff tears in people with shoulder pain for whom surgery is being considered. Cochrane Database Syst Rev. 2013;9:CD009020. doi:10.1002/14651858.CD009020.pub2.

57. Gyftopoulos S, Albert M, Recht MP. Osseous injuries associated with anterior shoulder instability: what the radiologist should know. AJR Am J Roentgenol. 2014;202(6):W541–50. doi:10.2214/AJR.13.11824.
58. Robinson CM, Howes J, Murdoch H, Will E, Graham C. Functional outcome and risk of recurrent instability after primary traumatic anterior shoulder dislocation in young patients. J Bone Joint Surg Am. 2006;88(11):2326–36.
59. Gooding BWT, Geoghegan JM, Manning PA. The management of acute traumatic primary anterior shoulder dislocation in young adults. Shoulder Elbow. 2010;2:141–6.
60. Handoll HHG, Almaiyah MA, Rangan A. Surgical versus non surgical treatment fior acute anterior shoulder dislocation. Cochrane Database of Syst Rev 2004;(1):CD004325.
61. Jaggi A, Lambert S. Rehabilitation for shoulder instability. Br J Sports Med. 2010;44:33–340.
62. Fedoriw WW, Ramkumar P, McCullock PC, Lintner DM. Return to play after treatment of superior labral tears in professional baseball players. Am Sports Med. 2014;42:1155–60.
63. Van Klenunen KP, Tucker SA, Field LD. Return to high-level throwing after combination infraspinatus repair, SLAP repair, and release of glenohumeral internal rotation deficit. Am J Sports Med. 2012;40:2536–41.
64. Mazzocca AD, Brown Jr FM, Carreira DS, Hayden J, Romeo AA. Arthroscopic anterior shoulder stabilization of collision and contact athletes. Am J Sports Med. 2005;33(1):52–60.
65. Petrera M, Dwyer T, Tsuji MR, Theodoropoulos JS.Outcomesofarthroscopic Bankart repair in collision versus noncollision athletes. Orthopedics. 2013;36(5):e621–6. doi:10.3928/01477447-20130426-25.
66. Handoll HH, Almaiyah MA, Rangan A. Surgical versus non-surgical treatment for acute anterior shoulder dislocation. Cochrane Database Syst Rev. 2004;(1):CD004325.
67. Paterson WH, Throckmorton TW, Koester M, Azar FM, Kuhn JE. Position and duration of immobilization after primary anterior shoulder DislocationA systematic review and meta-analysis of the literature. J Bone Joint Surg Am. 2010;92:2924–8.
68. Johnson AJ, Godges JJ, Zimmerman GJ, Ounanian LL. The effect of anterior versus posterior glide joint mobilization on external rotation range of motion in patients with shoulder adhesive capsulitis. J Orthop Sports Phys Ther. 2007;37:88–99.
69. Tokish JM, Decker MJ, Ellis HB, et al. The belly-press test for the physical examination of the subscapularis muscle: electromyographic validation and comparison to the lift-off test. J Shoulder Elbow Surg. 2003;12:427–30.
70. Werner CM, Favre P, Gerber C. The role of the subscapularis in preventing anterior glenohumeral subluxation in the abducted, externally rotated position of the arm. Clin Biomech (Bristol, Avon). 2007;22:495–501.
71. Lephart SM, Henry TJ. The Physiological basis for open and closed kinetic chain rehabilitation for the upper extremity. J Sports Rehabil. 1996;5:71–87.
72. Kibler WB. Closed kinetic chain rehabilitation for sports injuries. Phys Med Rehabil Clin N Am. 2000;11:369–84.
73. Kibler WB. The role of the scapula in athletic shoulder function. Am J Sports Med. 1998;26:325–37.
74. Kibler WB, Sciascia A. Rehabilitation of the athlete's shoulder. Clin Sports Med. 2008;27:821–31.
75. Gibson J, Elphinston J. Shoulder instability part III: treatment and rehabilitation of shoulder instability. Sportex Med. 2005;24:18–22.
76. Malliaras P, Morrissey D, Antoniou N. Rehabilitation of extreme sports injuries. In: Mei Dan O, Carmont MR, editors. Adventure and extreme sports injuries. London: Springer; 2013. p. 339–61.
77. Casazza BA. Diagnosis and treatment of acute low back pain. Am Fam Physician. 2012;85(4):343–50.
78. Foss IS, Holme I, Bahr R. The prevalence of low back pain among former elite cross-country skiers, rowers, orienteerers, and nonathletes: a 10-year cohort study. Am J Sports Med. 2012;40(11):2610–6.
79. Bahr R, Andersen SO, Løken S, Fossan B, Hansen T, Holme I. Low back pain among endurance athletes with and without specific back loading – a cross-sectional survey of cross-country skiers, rowers, orienteerers, and nonathletic controls. Spine (Phila Pa 1976). 2004;29(4):449–54.
80. Allen GD, Locke S. Training activities, competitive histories and injury profiles of elite boardsailing athletes. Aust J Med Sci Sports. 1989;21:12–4.
81. Ullis KC, Anno K. Injuries of competitive board sailors. Phys Sports Med. 1984;12:86–93.
82. Locke S, Allen GD. Etiology of low back pain in elite boardsailors. Med Sci Sports Exerc. 1992;24(9):964–6.
83. Allen JB. Sports medicine and sailing. Phys Med Rehabil Clin N Am. 1999;10(1):49–65.
84. Bouras T, Korovessis P. Management of spondylolysis and low-grade spondylolisthesis in fine athletes. A comprehensive review. Eur J Orthop Surg Traumatol. 2014;25 Suppl 1:S167–75.
85. Van Tulder MW, Assendelft WJJ, Koes BW, Bouter LM. Spinal radiographic findings and nonspecific low back pain: a systematic review of observational studies. Spine. 1997;22:427–34.
86. Witse LL, Newman PH, Macnab I. Classification of spondylolysis and spondylolisthesis. Clin Orthop. 1976;117:23–9.
87. Standaert CJ, Herring SA. Spondylolysis : a critical review. Br J Sports Med. 2000;34:415–22.
88. Rekand T. The epidemiology of injury in hang-gliding and paragliding. Med Sport Sci. 2012;58:44–56.

89. Rekand T, Schaanning EE, Varga V, Schattel U, Gronning M. Spinal cord injuries among paragliders in Norway. Spinal Cord. 2008;46(6):412–6.
90. Allen J, De Jong MR. Sailing and sports medicine: a literary review. Br J Sports Med. 2006;40:587–93.
91. Brinjiki W, Leutmer PH, Comstock B, Bresnahan LE, Deyo RA. Systematic literature review of imaging features of spinal degeneration in asymptomatic populations. AJNR Am J Neuroradiol. 2015;36(4):811–6.
92. Jarvik JG, Deyo RA. Diagnostic evaluation of low back pain with emphasis on imaging. Ann Intern Med. 2002;137:586–97.
93. Ogon M, Riedl-Huter C, Sterzinger W, Krismer M, Spratt KF, Wimmer C. Radiologic abnormalities and low back pain in elite skiers. Clin Orthop Relat Res. 2001;390:151–62.
94. Abenhaim L, Rossignol M, Gobeille D, Bonvalot Y, Fines P, Scott S. The prognostic consequences in the making of the initial medical diagnosis of work-related back injuries. Spine. 1995;20:791–5.
95. Henry SM, Fritz JM, Trombley AR, Bunn JY. Reliability of a treatment-based classification system for subgrouping people with low back pain. J Orthop Sports Phys Ther. 2012;42(9):797–805.
96. Delitto A, Erhard RE, Bowling RW. A treatment-based classification approach to low back syndrome: identifying and staging patients for conservative treatment. Phys Ther. 1995;75(6):470–85; discussion 485–9.
97. Fritz JM, Cleland JA, Childs JD. Subgrouping patients with low back pain: evolution of a classification approach to physical therapy. J Orthop Sports Phys Ther. 2007;37(6):290–302.
98. Bigos S, Bowyer O, Braen G, et al. Acute low back problems in adults. Clinical practice guideline no. 14. AHCPR publication no. 95-0642. Rockville: Agency for Health Care Policy and Research, Public Health Service, U.S. Department of health and Human Services; 1994.
99. Royal College of General Practitioners. Clinical guidelines for the management of acute low back pain. London: Royal College of General Practitioners; 1996 and 1999.
100. ACC and the National Health Committee. New Zealand acute low back pain guide. Wellington; 1997.
101. Danish Institute for Health Technology Assessment. Low back pain: frequency, management and prevention from an HTA perspective. Copenhagen, Denmark: Danish Health Technology Assessment; 1999.
102. Borkan J, Reis S, Werner S, Ribak J, Prath A. Guidelines for treating low back pain in primary care (Hebrew; available in English). The Israeli Low Back Pain. Guideline Group. Harfuah. 1996;130:145–51.
103. Faas A, Chavannes AW, Koes BW, Van den Hoogen JMM, Mens JMA, Smeele IJM, Romeijnders ACM, Van der Laan JR. Clinical practice guidelines for low back pain. (Dutch, available in English). Huisarts Wet. 1996;39:18–31.
104. Victorian Workcover Authority. Guidelines for the management of employees with compensable low back pain. Melbourne: Victorian Workcover Authority; 1993 and revised edition 1996.
105. Childs JD, Fritz JM, Flynn TW, Irrgang JJ, Johnson KK, Majkowski GR, Delitto A. A clinical prediction rule to identify patients with low back pain most likely to benefit from spinal manipulation: a validation study. Ann Intern Med. 2004;141(12):920–8.
106. Hicks GE, Fritz JM, Delitto A, McGill SM. Preliminary development of a clinical prediction rule for determining which patients with low back pain will respond to a stabilization exercise program. Arch Phys Med Rehabil. 2005;86:1753–62.
107. Flynn T, Fritz J, Whitman J, Wainner R, Magel J, Rendeiro D, et al. A clinical prediction rule for classifying patients with low back pain who demonstrate short-term improvement with spinal manipulation. Spine. 2002;27:2835–43.
108. McGill SM. Low back exercises: evidence for improving exercise regimens. Phys Ther. 1998;78: 754–64.
109. McGill SM. Low back stability: from formal description to issues for performance and rehabilitation. Exerc Sports Sci Rev. 2001;29:26–31.
110. Hodges PW, Richardson CA. Contraction of the abdominal muscles associated with movement of the lower limb. Phys Ther. 1997;77:132–42.
111. Hides JA, Richardson CA, Jull GA. Multifidus muscle recovery is not automatic after resolution of acute, first-episode low back pain. Spine. 1996;21: 2763–9.
112. Lee JH, Hoshino Y, Nakamura K, Kariya Y, Saita K, Ito K. Trunk muscle weakness as a risk factor for low back pain a 5-year prospective study. Spine. 1999;24:54–7.
113. McGill SM. Estimation of force and extensor moment contributions of the disc and ligaments at L4-L5. Spine. 1988;13:1395–402.
114. Oh YK, Lipps DB, Ashton-Miller JA, Woktys EM. What strains the anterior cruciate ligament during a pivot landing? J Sports Med. 2014;40:574–83.
115. Berneira O, Domingues R, Medeiros A, Vaghetti O. Incidência e caracterìsticas de lesões em practicantes de kitesurf. Revista Brasileira de Cineantropometria e Desempenho Humano. 2011;13(3):195–201.
116. Beaulieu ML, Oh YK, Bedi A, Ashton-Miller JA, Wojtys EM. Does limited internal femoral rotation increase peak anterior cruciate ligament strain during a simulated pivot landing? Am J Sports Med. 2014;42:2955–63.
117. Delincé P, Ghafil D. Anterior cruciate ligament tears: conservative or surgical treatment? A critical review of the literature. Knee Surg Sports Traumatol Arthrosc. 2012;20(1):48–61.
118. Scheffler SU, Unterhauser FN, Weiler A. Graft remodeling and ligamentization after cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc. 2008;16:834–42.

119. Mayr HO, Weig TG, Plitz W. Arthrofibrosis following ACL reconstruction – reasons and outcome. Arch Orthop Trauma Surg. 2004;124:518–22.
120. Saka T. Principles of postoperative anterior cruciate ligament rehabilitation. World J Orthop. 2014;5(4): 450–9.
121. Delitto A, Rose SJ, McKowen JM, Lehman RC, Thomas JA, Shively RA. Electrical stimulation versus voluntary exercise in strengthening thigh musculature after anterior cruciate ligament surgery. Phys Ther. 1988;68:660–3.
122. Snyder-Mackler L, Ladin Z, Schepsis AA, Young JC. Electrical stimulation of the thigh muscles after reconstruction of the anterior cruciate ligament. Effects of electrically elicited contraction of the quadriceps femoris and hamstring muscles on gait and on strength of the thigh muscles. J Bone Joint Surg Am. 1991;73:1025–36.
123. Adams D, Logerstedt D, Hunter-Giordano A, Axe MJ, Snyder-Mackler L. Current concepts for anterior cruciate ligament reconstruction: a criterion-based rehabilitation progression. J Orthop Sports Phys Ther. 2012;42(7):601–14.
124. Nyland J, Brand E, Fisher B. Update on rehabilitation following ACL reconstruction. Open Access J Sports Med. 2010;1:151–66.
125. Preobrazhenskiy V, Sidorenko E, Vnukov D, Preobrazhenskaya M, Lyadov K. The specialities of the early rehabilitation of alpine ski athletes after ACL reconstruction. Eu J Sports Med. 2013;1:12–178.
126. Fujiya H, Kousa P, Fleming BC, Churchill DL, Beynnon BD. Effect of muscle loads and torque applied to the tibia on the strain behavior of the anterior cruciate ligament: an in vitro investigation. Clin Biomech (Bristol, Avon). 2011;26:1005–11.
127. Ford KR, Myer GD, Schmitt LC, Uhl TL, Hewett TE. Preferential quadriceps activation in female athletes with incremental increases in landing intensity. J Appl Biomech. 2011;27:215–22.
128. Fitzgerald GK. Open versus closed kinetic chain exercise: issues in rehabilitation after anterior cruciate ligament reconstructive surgery. Phys Ther. 1997;77:1747–54.
129. Schmitt LC, Paterno MV, Ford KR, Myer GD, Hewett TE. Strength asymmetry and landing mechanics at return to sport after ACL reconstruction. Med Sci Sports Exerc. 2015;47(7):1426–34. doi:10.1249/MSS.0000000000000560.
130. Cozzi AL, Dunn KL, Harding JL, Valovich McLeod TC, Welch CE. Kinesiophobia following anterior cruciate ligament reconstruction among physically active individuals. J Sport Rehabil. 2014;24(4):434–9.

35

Legal Issues in Extreme Sport

Jon Heshka

35.1 Introduction

Any look at sports law – *lex sportiva* [1] – in general and extreme sports law must acknowledge that the body of law is unlike the human body in that laws and their applications vary from country to country, whereas the human body and its response to injury is remarkably the same regardless of the nationality of the participant. This holds true regardless of the cause whether it is due to impact of the law of gravity, to suffocation in an avalanche, or to other causal factors.

It is impossible to write the final word on the law of extreme sport to a global audience. Because legal doctrines, traditions, statutes, case law, and court systems differ worldwide, it is beyond the scope of this chapter to catalogue and describe how the law treats extreme sport around the planet. It is possible, in the broadest of brush strokes, however, to generally describe the law insofar as it interacts with extreme sport.

While theorists and sociologists may debate over the definition of what constitutes an extreme sport, for the purposes of this discussion, a sport is considered extreme if there is a real risk of severe injury, and it typically occurs in an adventure or outdoor setting. Hence, climbing is an extreme sport, but extreme Frisbee is not. Contact or collision sports like football or hockey are dangerous in their own rights – and that risk has risen to the level where the US-based National Football League agreed in 2015 to pay 1 billion USD to settle a class action lawsuit involving 4000 former players who alleged brain injuries caused or contributed by playing professional football in the NFL – but ice hockey and gridiron football are not considered extreme sports.

The law intersects with extreme sports at many points. The arenas of extreme sport which are now garnering the attention of the law include labor law and agency, intellectual property law, and ambush marketing, contracts, and torts. While the goings-on of Olympic and X Games snowboarding gold medalist Shaun White and his annual $10 million salary [2] and the influence on the industry exerted by Red Bull and their Brobdingnagian-sized billion dollar marketing budget [3] are interesting in their own right, this chapter shall instead focus more on how the law is activated after an extreme sport athlete sustains an injury. The law of tort looms large on this horizon and will be subsequently focused on. Case studies looking at incidents arising from luge, ziplining, climbing, and whitewater rafting will be used to illustrate and explore legal concepts throughout the chapter.

It is sometimes argued that sport in general and extreme sport in particular is beyond the reach of the law, that the law is ill-equipped to adjudicate disputes on and off the playing field, and that it is better left to the governing bodies

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charged with so doing. This argument is frequently raised by lawyers defending players or leagues sued by an injured plaintiff who will say that the courts do not possess the requisite expertise to navigate the nuances of sport in determining what is or is not reasonable conduct and should instead rely upon sports' governing bodies and leagues to mete out justice and act as judge, jury, and executioner.

To buttress that point, sport has developed a sophisticated legal system that climaxes at the Olympics with the Court of Arbitration for Sport whose rules appreciate that disputes must be decided in accordance with general principles of law and the rule of law [4]. Any sport which belongs to the Olympic movement – and regardless of how they are counted, there are a lot[1] – will have a mediation or arbitration process which is based on the CAS to which its athletes are contractually obligated to follow.

Notwithstanding this wishful thinking of defendant lawyers and sport's regulatory regime, the courts ruled long ago in *R. v. Bradshaw* [5] that "No rules or practice of any game whatever can make that lawful which is unlawful by the law of the land." In short, the long arm of the law will extend not only onto the football pitch or over the boards in ice hockey but to other extreme arenas where sport is carried out when there is just cause to do so.

35.2 Mainstreaming of Extreme Sport and Its Effect on the Law

Once marginalized and played by the lunatic fringe, extreme sport has become normalized and enormously popular. The popularity and commercial success of the X Games have made the Olympics take notice to the effect that the five interlocking rings have usurped extreme sport to maintain public interest and the steady flow of sponsorship dollars. Sensing ESPN's success with their first Winter X Games which showed that big air meant big money, the International Olympic Committee added snowboarding to the Nagano 1998 Winter Olympic Games, BMX racing to the Beijing 2008 Summer Olympic Games, and skicross to the Vancouver 2010 Winter Olympic Games. That ice climbing was included as a "cultural demonstration" sport at the Sochi 2014 Winter Olympics [6] and skicross, snowboarding and the half-pipe are now regularized in the Olympics are sure measure that extreme sports have gone mainstream.

Further, the International Olympic Committee approved big air in snowboarding and big air in freestyle skiing for the 2018 Winter Olympic Games in Pyeongchang, South Korea [7]. Big air snowboarding involves boarders flying off a highly pitched ramp similar and performing fantastical jumps with multiple flips and spins [8]. Notwithstanding that the injury risk for big air snowboarding is high [9, 10], event organizers continue to build higher and higher ramps to the extent that the 2015 X Games had Big Air athletes hurling off a 25.6-m jump [11]. These certainly aren't the Corinthian-styled Olympics of yesteryear.

Sport climbing was short-listed for inclusion at the Tokyo 2020 Olympics but failed to make the cut [12]. NBC, official broadcaster of the Olympics, opined that "with the Olympics growing ever more 'extreme,' don't be surprised to see it [sport climbing] someday [13]."

The mainstreaming of extreme sports has resulted not only in legitimizing these sports that formerly operated at the fringes but spawned an entire industry to support it and with that came the trappings associated with any successful business. The difference here though is that the services and products sold were intentionally designed to situate athletes in harm's way. This purposeful placement of the user into the jaws of death is at odds with how the law typically views the relationship between an actor and his environment which is ordinarily grounded in trying to make it as safe as possible.

This mainstreaming has led to its commodification and commercialization which has, in turn,

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[1] The sport England recognizes 147 sports, the London 2012 Olympics held 302 medal events in 39 disciplines, and the Sochi 2014 Olympics held 98 titles in 15 disciplines.

led to new potential sources of liability. Parties susceptible to a lawsuit in a competitive setting now include the International Federations for Olympic sports, their National Governing Bodies, event organizers, race officials, coaches, sponsors, broadcasters, referees, and officials, whereas parties vulnerable to a lawsuit in a noncompetitive environment do not include any of the aforementioned but instead could include equipment manufacturers, occupiers of the land, and athletic partners.

35.3 Negligence

To make out a claim of negligence, four elements must be shown: (1) damage or injury, (2) that there exists a duty of care between the injured person and the other party, (3) that there was a breach of the required standard of care, and (4) causation. Proximate cause and remoteness may modify a defendant's scope of liability.

The duty of care test is best articulated in the seminal case of *Donoghue v Stevenson* [14]:

> You must take reasonable care to avoid acts or omissions which you can reasonably foresee would be likely to injure your neighbour. Who, then, in law, is my neighbour? The answer seems to be – persons who are so closely and directly affected by my act that I ought reasonably to have them in contemplation as being so affected when I am directing my mind to the acts or omissions which are called in question.

By so framing the duty test around the neighbor principle, the parties potentially vulnerable to a lawsuit from an injured extreme sport athlete include the aforementioned national governing bodies, event organizers, race officials, coaches, sponsors, broadcasters, referees and officials, equipment manufacturers, occupiers of the land, film makers, and athletic partners.

Lord Atkin in *Donoghue* essentially said that mere foreseeability was not enough to establish the existence of a duty of care. A plaintiff also needs to show that they were sufficiently proximate to the defendant such that they should have been considered. Causation is the concept that links the plaintiff's damage with the defendant; to establish causation in law requires the court to be satisfied that the plaintiff would have suffered the injury but for the negligence of the defendant.

The court in *Blyth v. Birmingham Waterworks* [15] held that "Negligence is the omission to do something which a reasonable man guided upon those considerations which ordinarily regulate the conduct of human affairs, would do, or doing something which a reasonable and prudent man would not do." When determining whether the defendant has acted reasonably and met the required standard of care, the courts often look at three main factors: (1) probability and severity of the harm, (2) cost of risk avoidance, and (3) social utility or value of the conduct. These can be treated as qualifications or limits of reasonableness.

The paradox is that risk is the driving force behind the popularity of many extreme sports, so it becomes problematic strictly looking at the probability of injury. Further, the nature of the risks encountered and the extent to which these risks are inherent to extreme sport make it difficult if not impossible to avoid or eliminate the risks entirely. The risks of drowning while paddling big water, falling while climbing, or impacting the ground while performing big air BMX or snowboarding stunts cannot be eliminated if these extreme sports are to retain those essential elements that make them "extreme." Some courts have looked at the social utility or value of sport and have seemingly given them a pass from the ordinary negligence standard described here.

In establishing whether or not a duty exists, courts have been vexed by the extent to which a risk must materialize before it becomes unreasonable. Mere foreseeability fails as a test because it is clearly foreseeable that injury may arise while engaging in such extreme sports as BASE jumping, wingsuit flying, or speed skiing. So something more is required. The court in *Bolton v. Stone* [16] said that the test is whether the risk of damage to a person was so small that a reasonable person in the position of the defendants considering the matter from the point of view of safety would have thought it right to refrain from taking steps to prevent the danger.

The court also held that it is not reasonable to expect people to guard against risks that are “fantastic and farfetched.” Lord Porter said, “it is not enough that the event should be such as can reasonably be foreseen; the further result that injury is likely to follow must be also such as a reasonable man would contemplate, before he can be convicted of actionable negligence. Nor is the remote possibility of injury occurring enough; there must be sufficient probability to lead a reasonable man to anticipate it.”

Courts consider foreseeability to be a major consideration in the extent to which a duty is assigned and liability attached. In *Conway v. O'Brien* [17], Learned Hand J. stated that “The degree of care demanded of a person by an occasion is the resultant of three factors: the likelihood that his conduct will injure others, taken with the seriousness of the injury if it happens, and balanced against the interest which he must sacrifice to avoid the risk.” Hand later expressed these variables in an algebraic equation suggesting that the formula provides perspective on unreasonable risk: “If the probability be called P; the injury, L; and the burden, B; liability depends upon whether B is less than L multiplied by P; i.e., whether $B < PL$.”

Notwithstanding the above algebraic equation – which is pure in its mathematics but problematic in its application of the law to extreme sport – a defendant has breached the required standard of care when the conduct creates an unreasonable risk of harm. How is unreasonable risk of harm defined in extreme sport? Regarding negligence, it must also be shown that the breach which caused the plaintiff's damage in law is too remote to warrant recovery. The remoteness inquiry asks whether the harm is too unrelated to the wrongful conduct to hold the defendant fairly liable [18]. Since *Wagon Mound (No. 1)*, the principle has been that “it is the foresight of the reasonable man which alone can determine responsibility [19].” The degree of probability that would satisfy the reasonable foreseeability requirement was described in *The Wagon Mound (No. 2)* as a “real risk,” i.e., “one which would occur to the mind of a reasonable man in the position of the defendant … and which he would not brush aside as farfetched [19].”

The courts continue to struggle with how possible or probable a risk needs to be in order for it to be considered reasonably foreseeable and any breach to be considered unreasonable and therefore negligent. In light of the circumstances of extreme sport where the inherent risks are not only inseparable from the thing that makes these sports extreme but are the attractive force and why these athletes do it and where these risks are, for the most part, open and obvious, for there to be a finding of negligence, it would be necessary to show that the defendant event organizer materially breached the required standard of care by not sufficiently guarding against risks that are neither so small nor farfetched but lay in the realm of the reasonably – in the circumstances – probable in the arena of extreme sport.

The problem, of course, with the above analyses is that risk is exacerbated in extreme sport. Speeds are purposefully amplified, jumps are heightened, and stunts get trickier. This is not merely an exercise in reducing risk to a reasonable level because there is nothing inherently reasonable about these pursuits in the first place.

A tension arises between the raison d'être of extreme sports to push the envelope of what is possible by being unreasonable in its pursuit and the law which is essentially grounded in reasonableness. For there to be a finding of negligence, it must be shown that one party acted unreasonably toward another. This test or threshold is at the crux of the challenge with the law in finding fault in extreme or adventure sport as there is nothing inherently reasonable about it. Reasonable people do not heli-ski in avalanche terrain, duck under the ropes to enter closed areas at ski resorts, huck themselves off cliffs or huge jumps, etc.

Recall that the traditional negligence test judges a participant against the actions of a prudent and reasonable person. Participants of extreme sports are often anything but prudent, preferring to consciously, and occasionally carelessly, seek out hazardous situations, and accepting this risk as an inherent part of the activity. The law therefore has a delicate balancing act to perform between allowing individuals the autonomy to express and challenge themselves and taking a more paternalistic view and protecting participants from the consequences of their own actions [20].

Notions of negligence in extreme sport abut with principles of inherent risk and free will. In the seminal UK case of *Thomlinson v. Congleton Borough Council* [21] involving a young man who broke his neck while diving into a lake, the trial judge found that the danger and risk of injury from diving in the lake where it was shallow was obvious, that there was no duty to the landowner to warn against the danger, and that there were no hidden dangers. The judge noted that it is in the nature of lakes to be shallow in some spots and deep in others and that there was nothing that it made it more dangerous than any other ordinary stretch of open water in England.

The case was overturned on appeal with the court holding that the gravity of the risk, the number of people who regularly incurred it, and the attractiveness of the beaches around the lake created a duty. The majority of the Court of Appeal appeared to have proceeded on the basis that if there was a foreseeable risk of serious injury, the landowner was under a duty to do what was necessary to prevent it [22].

The House of Lords – the court of last resort up until 2009 – had the final word and held that insufficient weight had been given to the social value of the activity which gave rise to the risk, the cost of preventative measures, and the question whether the landowner should be entitled to allow people of full capacity to decide for themselves whether to take the risk.

Lord Hoffman wrote in the decision words which, while specific to the case, serve as words of wisdom to those who question the extent to which the law should intervene in extreme sport:

> I think it will be extremely rare for an occupier of land to be under a duty to prevent people from taking risks which are inherent in the activities they freely choose to undertake upon the land. If people want to climb mountains, go hang gliding or swim or dive in ponds or lakes, that is their affair. Of course the landowner may for his own reasons wish to prohibit such activities. He may think that they are a danger or inconvenience to himself or others. Or he may take a paternalist view and prefer people not to undertake risky activities on his land. He is entitled to impose such conditions. But the law does not require him to do so [23].

Another interesting case also arising out of the United Kingdom involved a young man who was critically injured while climbing. In 2002, Gary Poppleton went bouldering at an indoor climbing gym in Portsmouth, England. It was only his third or fourth time bouldering. He did not sign a disclaimer notice nor was he given any instruction or explanation of any risks. A sign, not displayed prominently, listed "Climbing Wall Rules," which included an injunction not to jump off the walls and not to climb on top of the structures, including the metal bars that cross the room. Poppleton was not shown the rules and he didn't read them. He attempted a leap from one wall to grab a buttress on an opposite wall, somersaulted in the air, and fell onto the shock-absorbent 12-in. matting on his head. The accident rendered him a quadriplegic.

In *Poppleton v. Trustees of the Portsmouth Youth Activities Committee* [24], the trial judge found Poppleton 75 % blameworthy and the activity center 25 % liable. Poppleton was granted a quarter of the approximately $8 million compensation award. The judge also considered the nature and extent of any common law duty of care owed to those of full capacity who chose to make use of a facility when the activity allowed is potentially dangerous to its participants. He addressed questions of foreseeability, proximity, and fairness. A duty could arise if a participant was offered training or supervision, but Portsmouth offered neither of these, and Poppleton did not ask for either. Poppleton's counsel felt that Portsmouth should have had a duty to operate an appropriate registration and induction process which would assess participants' competence and to offer training, supervision, and monitoring of the gym. It was also submitted that there is a significant difference between a landowner who may be under no duty to prevent people climbing his mountain and a commercial operator who creates a purpose-built place to enable and encourage hazardous activity.

The trial judge upheld the allegation that Portsmouth were in breach of duty in failing to warn Poppleton that the thick safety matting did not make a climbing wall safe but might induce or encourage an unfounded belief that it did. The defendants had a duty to warn him of dangers which were not obvious, and the matting was such a hidden or latent danger. The judge was satisfied that if Poppleton had been made aware that matting did not render falls entirely safe, he would not have attempted the leap in question. The judge found that the matting therefore created a false sense of security.

Notwithstanding that the matting was characterized as entirely adequate and appropriate by defendants' counsel, in regard to the characterization of the safety mat as a hidden or latent danger, it was not as absurd as it sounds. This is explained by the concept of risk homeostasis.

Risk homeostasis[2] is where people and systems unconsciously calibrate and accept a certain level of risk to maximize the overall expected benefit from an activity (i.e., antilock brakes and braking later; slower speed limits and tailgating closer; gridiron football helmets reduced the likelihood of skull and facial fractures but has created a sense of invulnerability that encourages players to collide more forcefully) [25]. Most significantly perhaps is that studies indicate that helmeted skiers go faster than non-helmeted skiers. Thus, a control measure designed to mitigate the risk in one area (such as helmets) is compensated by behavior such as skiing faster, hucking bigger air, skiing in the trees, or taking otherwise ill-advised chances which elevate the risk to its preexisting level.

The appeals court, however, was not so easily swayed. It considered the key points from *Tomlinson*: obvious risk, inherent danger, premises were not in a dangerous state, capacity and consent (free will), and duty (no duty to protect against obvious risk or self-inflicted harm). Portsmouth did not assume responsibility for Poppleton's safety. He was not offered nor did he request to be trained, supervised, or monitored. Hence, no duty was owed. In light of the above, the risk of a possibly severe injury from an awkward fall was plainly obvious and did not sustain a duty in Portsmouth to warn Poppleton of it. It was also quite obvious, the court ruled, that no amount of matting would absolutely avoid the risk of possible severe injury from an awkward fall and that the possibility of an awkward fall is an obvious and inherent risk of this kind of climbing.

There being inherent and obvious risks in the activity which Poppleton was voluntarily undertaking, the law did not require Portsmouth to prevent him from undertaking it nor to train him or supervise him while he did it. It made no difference to the analysis that Portsmouth charged Poppleton to use the climbing wall.

In the end, the appeals court stated that "Adults who choose to engage in physical activities which obviously give rise to a degree of unavoidable risk may find that they have no means of recompense if the risk materializes so that they are injured" [25] and deemed Poppleton 100 % responsible for the accident that left him paralyzed.

Though by no means precedent setting, *Thomlinson* and *Poppleton* are instructive in how courts are treating extreme sport. No longer the last refuge of scoundrels, while extreme sport makes millionaires and Olympians, it also injures or kills people in the process, and some of those who have suffered look to the courts for redress. The courts are increasingly denying claimant damages by recognizing the social utility of extreme sports and holding that these participants went in with eyes wide open fully either accepting the risks inherent to the activity or waiving their right to sue by signing a release of liability.

Criminal negligence and gross negligence occasion themselves much more rarely in extreme sport. The former is a criminal matter and the latter is a civil one, and while they are very different, what they have in common is that both require a very marked departure from the expected standard of care and a wanton or reckless disregard for the safety and well-being of another person.

The only known extreme sport case which has resulted in a criminal conviction for negligence involved a guided canyoneering trip going

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[2] Alternatively known as risk compensation theory [25]

horribly wrong. On July 27, 1999, 18 tourists and three guides died in a canyoneering incident in the Saxeten River in Switzerland. The guiding company which led the trip, Adventure World, proceeded with the trip despite a forecasted and visibly approaching storm. In his ruling, the judge noted that "safety is, and remains, the most important thing for a company like Adventure World." Three company directors were found guilty of negligent manslaughter for failing to establish a set of safety precautions to govern trips generally and for failing to cancel the 1999 trip in the face of dangerous weather. Each director received a 5-month suspended sentence and a fine of $4,600 whereas the three senior guides received even shorter suspended sentences and smaller fines; the two junior guides were acquitted of the charges [26].

35.4 Occupiers' Liability

There exist statutes which govern the rights and responsibilities of landowners or occupiers of premises. Notwithstanding differences in the legislation across jurisdictional boundaries, generally speaking the common features to any statute include the duty of the occupier to ensure that a person entering the premises is reasonably safe, by not creating a danger with the intent to do harm to the person or to act with reckless disregard to the safety of the person. The extent of the duty includes the condition of the premises, the activities on the premises, and the conduct of third persons on the premises.

Plaintiffs in ski resort accidents frequently claim the resort has failed in their duty to ensure the slopes are reasonably safe. Nearly all of these claims have failed because the courts find that the plaintiffs accept the mountains as they are and that they have voluntarily assumed the risks ordinarily inherent to the activity of skiing or snowboarding or have contracted out liability by having signed a waiver.

The extreme sports of skicross, snocross, and big air may test the extent to which inherent risk and the voluntary assumption of risk may immunize occupiers and, in this instance, event organizers from liability. The reason for this is because race courses or jumps are purposefully designed and sculpted to make for fast courses and high jumps. The organizers effectively control the amount of risk to be engineered into the event. There exists therefore a tension between keeping the course reasonably safe and not dangerous versus building something that is true to the spirit of extreme sport and exciting to the athletes and fans.

Nik Zoricic died in a World Cup skicross race in Switzerland in 2012. He crashed into the nets on the side of the course after the final jump near the finish line. The lawyer representing Zoricic's family called Zoricic's death the result of gross negligence of race organizers and officials and threatened to sue unless there were changes to the sport. The lawyer alleged the jump trajectory was improper, the snow and snow bank were improperly groomed, the final jump was too close to the finish line, the jump zone was too narrow and that the fencing used was improper [27]. Some officials described Zoricic's death a result of "pilot error" effectively saying he was contributorily negligent or a "freak accident" meaning it was the unfortunate by-product of the risks inherent to the extreme sport of skicross. The Zoricic family pressed the International Federation for skicross (FIS or the International Ski Federation), and after 2 years of discussions, FIS unequivocally released a letter saying that "It would therefore not be right to describe his [Zoricic's] accident as a "freak accident" or "pilot error" and promised changes to the way skicross races are run [28].

Georgian luger Nodar Kumaritashvili died while on a training run on the opening day of the 2010 Vancouver Olympic Winter Games. The initial approach of the Vancouver Organizing Committee for the 2010 Olympic and Paralympic Winter Games (VANOC) was to also blame Kumaritashvili and attribute his death due to pilot error. The BC Coroner's Report similarly stated that his relative lack of experience set the backdrop for the incident. While no doubt relatively inexperienced compared to the top lugers from Europe and North America, Kumaritashvili qualified to compete and deserved to be there.

This track was intentionally engineered for world-record-breaking speed and high G-forces. A high-speed corner was named “50–50” due to the odds of making it without crashing. World-class lugers were crashing in their limited training runs. What happened was not just due to the inherent risks of the luge or to Mr. Kumaritashvili’s inexperience. The chief executive officer of VANOC expressed concern that an athlete could get “badly injured or worse” on the high-speed track, and organizers might be accused of doing nothing to prevent it. The president of the governing body for luge, the International Luge Federation (FIL), was worried about the track speed as FIL’s goal was to have tracks around 135 km/h, but the Whistler track had racers hitting speeds of 154 km/h. The president acknowledged that it would be an absolute unreasonable demand for athletes if they were unable to cope with these extremely high speeds.

While Kumaritashvili’s death did not lead to litigation and nobody was held liable, all the ingredients were present which would have made for an interesting extreme sports law case: an International Federation, the Olympics, event organizers, negligence, occupiers liability, waivers, inherent risk, and voluntary assumption of risk. Nodar Kumaritashvili’s family received a $150,000 insurance payout from VANOC.

35.5 Waivers

A common means of defense against a lawsuit is to transfer the liability back to the participant by means of a waiver. A waiver is basically a legal instrument that, when properly prepared and presented, shields the party proffering it. Waivers are used interchangeably with releases of liability, indemnities, and covenants not to sue and are designed to allocate or shift legal responsibility for wrongdoing causing personal injury or death to another person.

Waivers are contentious because of the effect they have in protecting the party proffering it. Their efficacy in some jurisdictions is notoriously unreliable, while their reliability in other jurisdictions makes them a valid risk management tool and a means of transferring liability back to the participant.

Since the effect of a waiver is to negate the duty of the party relying upon it to take reasonable care for the safety of the persons signing it, courts are careful, and occasionally hostile, to upholding them. In the context of extreme sport, the waivers would be administered by governing bodies and/or event organizers, and the persons signing it would be athletes.

Are waivers worth the paper they’re printed on? This question is often rhetorically asked with the mistaken belief that they are not, but, depending on the jurisdiction and the facts of the case, its answer is actually “maybe.” In the best quantitative analysis of appeal court judgments where defendants wished to rely upon their waiver as central to their defense, in 44 Canadian cases over four decades, 22 were disposed in favor of the plaintiff and 22 in favor of the defendant [29].

The two leading extreme sport cases in Canada where the role of waivers was central to the cases’ outcome involved whitewater rafting and ziplining. In *Delaney v. Cascade River Holidays Ltd* [30], Dr. Fergus Delaney died after being tossed from a raft following a collision with a rock on a commercially guided trip on the Fraser River in British Columbia. Dr. Delaney’s wife sued alleging negligence and that the waiver he signed was not enforceable. The trial court agreed that it was overturned on appeal in a complex ruling which held that Dr. Delaney had been given sufficient consideration and notice of the waiver – which generally mentioned loss or damage but not the risk of injury of death – he signed on the morning of his death.

In *Loychuk et al. v. Cougar Mountain Adventures Ltd*. [31], after having been authorized to proceed by the guide, one participant in a commercial zipline operation violently collided at high speed into another participant who had stopped midline. The resultant collision injured both women. At the trial, the zipline operator admitted the guides were negligent by improperly allowing Ms. Loychuk to begin her descent down the zipline without ensuring the line was free and clear. Cougar Mountain admitted that the accident had been caused by the negligence of one of its employees and relied in its defense upon its waiver which clearly stated that negligence on the part of Cougar Mountain including the failure to take reasonable steps to safeguard or protect participants from the risks, dangers, and hazards of riding the zipline. The BC Supreme Court found in favor of Cougar Mountain and the judgment was upheld at appeal. In upholding the trial court's decision in favor of Cougar Mountain, the appeals court found that it was neither unconscionable nor against the public interest for negligence to be one of the risks to be assumed in the waiver by the claimants [32].

The inclusion of negligence as a term in a release of liability, waiver of claims, and assumption of risk agreement is unusual and is not the norm in other jurisdictions. It is not apt to be upheld in the United States and is expressly prohibited in the United Kingdom as The Office of Fair Trading and the Unfair Contract Terms Act disallow it.

American courts have routinely upheld waivers in extreme sport cases involving climbing. In *Delk v. Go Vertical, Inc.* [33], the US District Court of Connecticut held that the climbing gym's waiver and release of liability was valid and enforceable in a 2004 case where a 21-year-old woman sustained severe spinal injuries after falling from a height of 16 ft while bouldering. Matters relating to matting, supervision, failure to warn, and the sundry other allegations were rendered irrelevant and not even contemplated by the court, as the waiver acted as a complete bar to recovery.

A similar outcome occurred a year earlier in another bouldering case, *Lemoine v. Cornell University* [34], when the New York Supreme Court Appellate Division enforced the university's release as unambiguously acknowledging the inherent risks of climbing. In *Holbrook v. McCracken*, the plaintiff climber sued his partner for negligent belaying while he was descending a climbing-gym wall. The Court of Appeals of Ohio held that the injury was due to an inherent risk of climbing, i.e., falling, and barred recovery. Similarly, the Michigan Court of Appeals ruled in *Mankowski v. Mieras* [35], a 1999 climbing-gym case in which a climber decked while leading a route, that belayer negligence is an inherent risk to be assumed.

35.6 Child Endangerment

In the aftermath of the avalanche which killed two people while snowmobiling during the Big Iron Shootout on Boulder Mountain in British Columbia, Canada, in 2010 and which had minors spectating the high-marking contest as they stood in an open and obvious avalanche trap, it was decided that there was insufficient evidence to pursue criminal negligence or child neglect and endangerment charges to those who took the kids to the Shootout.

Also in 2010, American 13-year-old Jordan Romero became the youngest person to climb the 8848-m Mt. Everest. He became a cause célèbre while also earning the enmity of some who believe the risks of climbing such a peak are too great for a child to assume. To wit, Nepal does not issue permits to climbers under the age of 16 years, and at least one reputable guiding outfit, International Mountain Guides, does not allow climbers less than 18 years of age to go on Everest expeditions.

Jordan had never climbed any of the world's 14 8000-m peaks. He was guided up Mt. Everest by his father and three Sherpa guides from the Tibetan side where no such regulations or restrictions exist for children climbing the peak.

Six climbers die for every 100 who summit Mt. Everest; more than 265 have died on the mountain since 2014 [36]. The risks are very real and are not to be mistaken for the legal debates about whether the risks encountered are remote, farfetching, or fantastical.

This raises some interesting legal questions about minors and extreme sport. To what extent is a minor capable to make an informed decision and an uncoerced choice to either sled in potentially hazardous avalanche conditions in the backcountry – in the instance of the Big Iron Shootout – or climb the world's highest mountain? What role do parents play in encouraging or discouraging their child in such circumstances? Should kids even be allowed to pursue such extreme adventures in the first place?

Jean-Pierre Herry, a medical doctor from Ecole Nationale de Ski et d'Alpinisme (ENSA: the French National Ski and Mountaineering

School), states that it is not advisable for children under the age of 16 to ascend Mont Blanc which stands 4810-m above sea level [37]. David Hillebrandt, a medical adviser to the British Mountaineering Council, believes that 13 is too young to be exposed to such high altitude and that guiding someone of that age up to Mt. Everest borders on child abuse [38].

Canadian and American courts have not yet had to confront the issue of child endangerment and extreme adventure. It is fortunate that no minors died in the Boulder Mountain snowmobiling avalanche and that Jordan did not perish on Mt. Everest. The role luck plays in extreme sport should not be underestimated and we should not kid ourselves that skill alone can prevent death or injury in such circumstances.

It is noteworthy that a Dutch court in 2011 briefly placed then 13-year-old Laura Dekker into state care to stop her attempt to become the youngest person to sail solo around the world and held that it would have been irresponsible to permit her to undertake such a venture into extreme circumstances. The Council for Child Protection, the Dutch government's umbrella childcare agency, was unsuccessful in asking the court to extend the protective order for a further year; she eventually sailed 27000 nautical miles to become the youngest person at 16 years and 123 days to circumnavigate the globe [39].

As it becomes ever more commonplace for ever younger children to participate in such extreme sports, it is only a matter of time before a child is killed and that the courts will be invited to weigh in on whether or not the child's parents are complicit and culpable in their child's death.

References

1. Siekmann RCR, Soek J. Lex sportiva: what is sports law? Springer; 2012.
2. Celebrity Net Worth. http://www.celebritynetworth.com/richest-athletes/olympians/shaun-white-net-worth/. Accessed May 2015.
3. Sylt C. Revealed: red bull's $1.2 billion bet on formula one (April 3, 2014). Forbes. http://www.forbes.com/sites/csylt/2014/04/03/revealed-red-bulls-1-2-billion-bet-on-formula-one/. Accessed June 2015.
4. Court of arbitration for sport – arbitration rules for the olympic games. http://www.tas-cas.org/fileadmin/user_upload/CAS_adhoc_rules_Olympic_Games_London_2012.pdf. Accessed June 2015.
5. Cox CC. Cox's criminal cases. 14:83;1878.
6. Osius A. TNB: ice climbing goes to sochi olympics. Rock and ice. http://www.rockandice.com/lates-news/ice-climbing-goes-to-sochi-olympics. Accessed June 2015.
7. Knoblauch A. Four new events approved for 2018 Winter Olympics Games. LA Times. 8 June 2015. http://wwwl.latimes.com/sports/sportsnow/la-sp-sn-new-events-winter-olympics-20150608-story.htm. Accessed June 2015.
8. Wilson S. IOC approves big air snowboarding, mixed doubles curling for 2018 pyeongchang olympics. National Post. 8 June 2015. http://news.nationalpost.com/sports/olympics/ioc-approves-big-air-snowboarding-mixed-doubles-curling-for-2018-pyeongchang-olympics. Accessed June 2015.
9. Torjussen J, Bahr R. Injuries among elite snowboarders (FIS snowboard world cup). Br J Sports Med. 2006;40(3):230–4. doi: 10.1136/bjsm.2005.021329. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2492000/. Accessed June 2015.
10. World Snowboard Tour. "Risks in big air snowboarding – the world snowboard tour" in https://www.youtube.com/watch?v=RfXx1f8nk7o. Accessed June 2015.
11. Hendricks H. X games 15 big air finals, McMorris claims gold. Transworld snowboarding (23 Jan 2015). http://snowboarding.transworld.net/photos/x-games-15-big-air-finals-mcmorris-claims-gold/#8167+53fa736774#dVkQ6VhRTsOtWSRB.97. Accessed June 2015.
12. Gardner T. Climbing and the olympics. British Mountaineering Council (15 Mar 2013). https://www.thebmc.co.uk/climbing-and-the-olympics-2. Accessed June 2015.
13. Kitchen M. Sport climbing's pitch for the 2020 olympics. NBC OlympicTalk (28 May 2013). http://olympictalk.nbcsports.com/2013/05/28/sport-climbings-bid-for-the-2020-olympics/. Accessed June 2015.
14. UKHL (United Kingdom House of Lords) 100:44, 1932 SC (HL) 31.
15. EWHC (England and Wales High Court) Exch J65; 1856: 11 Exch (Exchequer) 781; 156 ER (England Reports) 1047.
16. AC (Court of Appeal) 850; 1951: 1 All ER (All England Law Reports) 1078.
17. U.S. Court of Appeals for the Second Circuit – 111 F.2d 611 (2d Cir. 1940).
18. Linden AM, Feldthusen B. Canadian Tort Law, 9th edn. LexisNexis Canada; 2011, p. 360.
19. SCC (Supreme Court of Canada): 2008; 27 at 120.
20. Lines K, Heshka J. Falling in line with the law – should adults who are injured after deliberately putting themselves at risk expect to be compensated? N Law J. 2008:1026–7.

21. UKHL (United Kingdom House of Lords). 2003; 47.
22. EWCA Civ (England and Wales Court of Appeal Civil Division). 2002;309.
23. UKHL (United Kingdom House of Lords). 2003; 47 at 45.
24. EWCA Civ (England and Wales Court of Appeal Civil Division). 2008; 646: (1) (May LJ). All ER (All England Law Reports); (D) 150 (Jun).
25. Wilde GJS. The Theory of Risk Homeostasis: Implications for Safety and Health. Risk Analysis. 1982;2:209–25.
26. Olson E. Swiss judge convicts six in deaths of adventurers lost in flood. The New York Times. 12 Dec 2001. http://www.nytimes.com/2001/12/12/world/swiss-judge-convicts-six-in-deaths-of-adventurers-lost-in-flood.html. Accessed June 2015.
27. Danson T. Zoricic family sets deadline for investigation. 6 Mar 2013. http://timdanson.com/2013/03/06/zoricic-family-sets-deadline-for-investigation; News Release. Accessed June 2015.
28. International Ski Federation Letter Re: The Legacy of Nik Zoricic. 3 Mar 2014. http://timdanson.com/wp-content/uploads/2014/03/FIS-Letter-to-Zoricic-Family_03-03-14.pdf. Accessed June 2015.
29. Manitoba Law Reform Commission's Waivers of Liability for Sporting and Recreational Injuries, p. 18. http://www.manitobalawreform.ca/pubs/pdf/120-full_report.pdf. Accessed June 2015.
30. 1983 CanLII 387 BCCA (British Columbia Court of Appeal); 44 BCLR (British Columbia Law Reports) 24; 24 CCLT (Canadian Cases on the Law of Torts) 6.
31. BCCA (British Columbia Court of Appeal). 2012:122.
32. The Court of Appeal for British Columbia relied upon the Supreme Court of Canada's judgment in *Tercon Contractors Ltd. v. British Columbia (Transportation and Highways),* 2010 SCC (Supreme Court of Canada) 4 (CanLII) 2010; 1 S.C.R. 69 in its analysis.
33. United States District Court, D. Connecticut. 2004; Feb 3 303 F.Supp.2d 94.
34. Appellate Division of the Supreme Court of the State of New York, Third Department. 11 Dec 2003. 2 A.D.3d 1017; 769 N.Y.S.2d 313.
35. Mich. App. LEXIS 514; State of Michigan Court of Appeals. 1999; 12 Mar.
36. Green S. Death on mount everest. The figure is actually 6.5%. http://climbing.about.com/od/mountainclimbing/a/Death-On-Mount-Everest.html. Accessed June 2015.
37. Griffin L. Jordan romero on everest. British mountaineering council. 26 May 2010. https://www.thebmc.co.uk/jordan-romero-on-everest. Accessed June 2015.
38. Barkham P. Should a teenager be climbing Mount Everest. The Guardian. 2010; 12 Apr. http://www.theguardian.com/world/2010/apr/12/should-teenager-climbing-mount-everest. Accessed June 2015.
39. Davies C. Dutch 14-year-old's plan to sail round world backed by court. The Guardian 2010; 27 July. http://www.theguardian.com/world/2010/jul/27/dutch-sailing-laura-dekker. Accessed June 2015.