Mechanics, Pathomechanics and Injury in the Overhead Athlete

A Case-Based Approach to Evaluation, Diagnosis and Management

W. Ben Kibler
Aaron D. Sciascia
Editors

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This book is dedicated to all the overhead athletes who derive enjoyment, meaning, and purpose through their sports activities and the clinicians who work to provide the best care.

—W. Ben Kibler

This book is dedicated to my father, David, for teaching me to enjoy America's pastime.

—Aaron D. Sciascia

Foreword

Participation in athletics offers many rewards including physical dominance, individual and shared success, record setting opportunities, public adornment, and adoration. However, the inherent trade-off of obtaining the reward is exposing oneself to the risk, i.e., injury. Much has been written concerning the evaluation and treatment of upper extremity injury in overhead athletes. Those works have provided a wealth of practical information regarding injury incidences, evaluation techniques, surgical techniques, rehabilitation protocols, and patient outcomes, all of which have guided clinical practice. However, although most of the published information has alluded to treating the patient as an individual, the end products were often global guidelines focused on a single sport or all overhead athletes collectively. The unique qualities and demands of each overhead sport as well as each overhead athlete seem to call for a comprehensive resource that practitioners could turn to for assistance in order to treat each patient as an individual. After years of interacting with overhead athletes from various sports in the clinical setting as well as providing our own contributions to the literature on the subject, we felt a textbook needed to be written for clinicians that not only contains our evaluation and treatment philosophy but also provides specific case examples of the most common patient presentations and symptoms as well as the clinical evaluation and management specific to each patient scenario. To accomplish the goal of this project, we invited and secured commitments from some of the highly recognized experts who routinely evaluate and treat the gamut of overhead athletes. Their contributions helped us find balance between offering global principles of patient care with specific case examples. The global principles include an understanding of why the patient is in the clinician's office, the mechanics and pathomechanics of various overhead sports, the role of the scapula in overhead function, load versus overload, basic surgical and rehabilitation principles, and return to activity and recovery. Following the presentation of the principles, we attempted to include a multitude of cases with a variety of patient ages, sports, and symptoms as well as the clinical thought process related to the evaluation and management decisions. We firmly believe all clinicians can utilize this resource, and we hope it can lead to optimal patient outcomes for each individual patient.

Richmond, KY, USA Aaron D. Sciascia, PhD, ATC, PES

Preface

Many excellent books, with content supplied by leading authorities in the field, have been written about the overhead athlete. The volume of the literature reflects the widespread interest in this subject, the high levels of participation in the activity, the impact this activity has on sports performance, and the desire to improve performance and modify injury incidence and risk. When Dr. Sciascia and I were approached about editing and producing another book on this subject, we recognized the need to take a slightly different approach to presenting the current knowledge and concepts and stimulating discussion and clinical application. As a result, this book is divided into two complementary sections.

The first section, the "basics," is designed to provide the reader with the basic science regarding mechanics, pathomechanics, and load around the shoulder and elbow in the overhead athlete, principles of evaluation and examination, principles of surgical treatment and rehabilitation of the shoulder and elbow, principles for return to play, and principles of risk modification. This section will provide the information base for management of the cases.

The second section is organized around clinical cases involving shoulder and elbow dysfunction in all types of active overhead athletes. It is designed to meet the reader where they spend most of their clinical time in the office, evaluating the clinical presentation of the shoulder and elbow dysfunction, formulating the comprehensive diagnosis, and formulating and implementing the treatment. The 20 cases represent the spectrum of age, sex, participation level, injury location, injury type, and treatment considerations that may be seen in this diverse population. The cases were specifically selected to provide the widest exposure for the reader. Each case is presented in a format that is similar to that which each clinician will follow in the patient interaction – the evaluation, formulation and discussion of treatment options, implementation of treatments, and determining outcomes – so that the clinician will understand the entire process. The authors for each case were selected specifically for their expertise in the clinical area covered by the case.

We hope the reader will enjoy and benefit from the case-based format and expect they will be able to apply the principles demonstrated in the case for all types of similar clinical problems. Scholarship regarding the overhead athlete is continuing to expand, resulting in more basic science knowledge, better knowledge of the pathophysiology and pathomechanics of injury, and more precise treatment protocols. It is also hoped that this book will contribute to raising the bar for current clinical concepts and will be a stimulus to develop future investigations and concepts.

Lexington, KY, USA W. Ben Kibler, MD

Acknowledgment

Any book author or editor stands on the shoulders of many colleagues. In my career working with overhead athletes, I have had the benefit and pleasure of associating with and learning from Drs. Frank Jobe and Lew Yocum, two pioneers in baseball sports medicine, who provided for me a strong base of understanding in this subject, an example of compassionate caring, and stimulated a lifelong desire to improve my capabilities. Other major contributors to my clinical knowledge include Dr. Robert Leach, Dr. James Andrews, Dr. Russ Warren, Dr. Steve Burkhart, and Dr. Buddy Savoie. In addition, my medical colleagues at the Shoulder Center of Kentucky and our rehabilitation staff have provided excellence in care and in research, helping increase the scholarship and improve the outcomes. My coeditor, Dr. Aaron Sciascia, has been a consistent colleague in both research and education. Finally, the authors of all the chapters deserve special recognition. All of them undertook their chapter with enthusiasm, provided excellent content, and were a pleasure to work with.

Special acknowledgment is due to my wife of 49 years, Betty, my foundation and wise counsel, who has supported me in many tangible and intangible ways through my long adventure in sports medicine. The most important acknowledgment is to God, the Creator of this wonderful body and who has continued to provide wisdom and guidance to me in my career.

—W. Ben Kibler

To acknowledge all of the people who have impacted my life and career could likely fill a book of its own. However, there are three individuals who must be noted because of their direct influence on me and this book:

First, Michael Higgins, PhD, PT, ATC, for teaching me how to be a practical clinician. Your influence is felt throughout this text.

Second, my longtime mentor, colleague, and friend, Tim Uhl, PhD, ATC, PT, FNATA, for teaching me how to be constructively critical and how to think at a level I never considered possible.

Finally, W. Ben Kibler, MD, my coeditor, mentor, and counselor. Thank you for pouring your knowledge into me the past 15 years and always holding me accountable.

—Aaron Sciascia

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Part I

Basics

1

Mechanics of the Overhead Motion

Stephen J. Thomas

Introduction

The overhead motion involves a series of complex full-body movements that are precisely timed to allow maximal velocity of the distal segment. Having an understanding of normal mechanics and how to teach these complex movements to athletes is essential in enhancing performance and mitigating injury [1].

Due to the high-speed nature and use of multiple segments, it is difficult to assess upper extremity mechanics with the naked eye. Therefore, teaching mechanics should attempt to simplify the process into basic steps with a particular goal in mind. For example, in throwing, athletes can be told that when they step with their stride leg, their arms should also begin to move apart with the goal of having their arm at shoulder level when their foot contacts the ground. This strategy will allow each athlete to utilize the CNS in their own unique way to accomplish that goal. With practice and repetition, the CNS coordination will be refined but always centering around the goal that was stated.

Faulty mechanics typically occur for two reasons: (1) improper teaching and/or (2) mechanical compensations related to overuse or fatigue [2–6]. If the overhead mechanics are being taught incorrectly, it is likely that these erroneous mechanics will remain throughout the players' career. Typically the improper mechanics will increase stress on the stabilizing joint structures [7–10], which will lead to overuse injuries that may even require surgical intervention. Interestingly, mechanics may be optimal at the youth level but due to overuse may develop into mechanical deficits or compensations due to fatigue or pain [11–13]. These compensations are very difficult to identify as they develop very gradually overtime.

The high stress and large repetitions that are known to occur in overhead sports often lead to structural and biomechanical adaptations [14–30]. At times these adaptations are beneficial to the athlete by enhancing performance and preventing injury. However, many of these adaptations are often detrimental to the athlete and lead to degeneration of specific tissues that ultimately cause significant damage and pain [28, 29, 31–33]. The most common adaptations will involve range of motion (tightness or laxity of specific tissues) [24–28, 34–39], strength and fatigue of specific muscles [40–45], and/or neuromuscular control (coordination and recruitment of muscles to perform a given task) [15, 46–49]. These specific tissue adaptations can be associated with alterations in the overhead motion. In fact, motion compensations often will accelerate this process by further exacerbating the stress on specific tissues. Therefore, this is thought of as a negative feed-

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back loop that is often difficult to stop without temporarily discontinuing the overhead motion. During this time correcting the specific tissue adaptations with a structured exercise prescription is required. These specific adaptations will be discussed in detail in the Pathomechanics chapter.

Since there are several sports that fall under the category of "overhead," it is important to examine the mechanics of each sport separately. The mechanics associated with each sport can vary drastically and therefore will be covered in detail throughout this chapter. As was discussed previously, identifying motion compensations is difficult, however critical in preventing injuries. Therefore, the most common motion compensations will also be discussed in detail for each sport.

Baseball

Baseball pitching is the most studied overhead sport in terms of biomechanics and injury prevention. This is likely due to the high injury rates of shoulder and elbow injuries that occur compared to other overhead sports [50]. Baseball pitching produces the largest forces and torques at the shoulder and elbow along with a very large number of repetitions throughout a season [7, 8, 10, 51]. This combination may not allow full tissue recovery of the tendons and ligaments thereby leading to cumulative microdamage or degeneration, which overtime could ultimately cause frank tearing.

Baseball pitching has been divided into very specific phases of motion. Each phase has specific goals, and there may be individual and unique ways of reaching the goal for each of the phases. Baseball pitching has been commonly divided into five phases (windup, early cocking, late cocking, acceleration, deceleration/follow-through) [52, 53].

Windup

Windup is the least stressful phase of pitching; however, it should not be thought of as the least important. The goal of this phase is to initiate lower extremity involvement and energy generation and maintain balance. During this phase, the lead foot will leave the ground and move up toward the waist of the player. This is commonly referred to as the leg kick. Every player's leg kick can vary dramatically, and there has not been any research to suggest that a certain leg kick is optimal for energy generation. From a biomechanical perspective, the leg kick will raise the center of mass of the pitcher. This has the potential to lead to increased amounts of potential energy prior to striding down the mound. Some players not only elevate their front leg toward their waist, they will also rotate their pelvis toward second base. This is thought to pre-stretch the hip external rotators on the stance leg, which can cause a stretch reflex resulting in more explosive acceleration down the mound. Another aspect of windup is lateral trunk tilt toward second base. This will move the center of mass posterior, positioning it above the stance leg. Research has demonstrated that increased vertical ground reaction forces on the stance leg are linked to increased stride length, [54] which has been related to performance and joint loads [55–59]. This is what pitching coaches often refer to as "loading the back leg." Since a large portion of lower extremity energy production is created from ground reaction forces, a proper windup can position the player appropriately to maximize force development later in the early cocking phase. Balance is the final aspect of windup that is very important.[60, 61] Throughout the entire windup phase, the player has to balance on one leg. In order to produce maximal energy from the lower extremity, the center of mass needs to be positioned in the correct location and stable. This requires well-developed preprogrammed patterns of muscle activations to stabilize all of the joints and reduce the degrees of freedom in the entire leg [62, 63]. If the center of mass is unstable and going through large excursions, energy will be wasted in larger muscle contractions attempting to control and reposition the center of mass [2, 64]. There are numerous reasons that pitchers can lose their inability to maintain balance during single leg stance. Chronic instability in either the ankle or knee or disorders affecting any one of the balance centers throughout the body can lead to balance deficits

[65–67]. Anecdotally, in baseball it has been thought that balance deficits are related to core and hip weakness. This can be linked to the repetitive overuse of baseball pitching leading to chronic neuromuscular fatigue; however, this is only speculated. Interestingly, programs designed to address hip and core weakness have demonstrated marked improvements in balance [68].

Early Cocking

Early cocking is started when the ball and glove hand separate and end when the stride foot contacts the ground. Forces and torques during this phase of pitching are insignificant [7]; however, it has the potential to greatly affect the outcomes of the next three phases of the pitch. This also happens to be the most coachable phase of pitching since velocities and accelerations are minimal compared to the remaining three phases. The goals of this phase are to generate large amounts of energy with the stance leg, create momentum of the entire body, get the shoulder in a position to throw, properly time the lower and upper bodies, and properly position the stride leg to maximize elastic energy.

In the windup phase, it was discussed that the stance leg is "loaded." Once the hands begin to separate, the stance ankle, knee, and hip begin to flex similar to a squat. This converts potential energy of the high center of mass into kinetic energy. This also helps to pre-stretch the ankle, knee, and hip extenders that will be working together to accelerate the body down the mound. It is very important that the center of pressure is directed near the heel of the stance foot. This allows the resultant ground reaction force to be pointed toward home plate thereby directing all acceleration of the body toward the intended target [54]. Two common alterations can occur during this time. The first is weakness of the lower extremity, especially the quadriceps. This weakness will lead to uncontrolled lowering of the stance leg, which often prevents the pitcher from optimally lowering the center of mass to maximize kinetic energy and storing elastic energy from all three lower extremity joints. Second, limitations are often observed in ankle dorsiflexion of the stance leg. While the ankle, knee, and hip are lowering into flexion, end range of ankle dorsiflexion can occur early causing the hip to compensate and move into greater amounts of flexion. This causes both the center of mass and the knee to move anterior to remain balanced. The center of pressure within the stance foot can shift toward the toes, which leads to early heel lift. Ultimately, this moves the resultant ground reaction force vector away from the optimal center directed line, often referred to as the "driveline," toward home plate. The pitcher often lands "closed off" or "across their body." This can delay the timing of the pelvis and trunk in later phases [69] and also have *linear momentum* = (*mass* × *velocity*) directed off the driveline, thereby not contributing optimally to ball velocity.

As the ankle, knee, and hip begin to explosively extend and create the resultant ground reaction force vector along the driveline, the entire body is accelerated down the mound creating linear momentum. The ability of the stance leg to get full explosive extension of all three joints will allow for a larger ground reaction force resuting in greater velocity. The equation for linear momentum also demonstrates that if velocity is held consistent, a larger mass will create more momentum. This has been demonstrated in biomechanical studies which have found relationships between body mass and ball velocity [70]. At this point in the pitching motion, only the lower extremity has produced force; however, the entire body possesses linear momentum [59]. When the lower extremity doesn't create maximal linear momentum, the upper extremity will have to compensate with the use of smaller muscles compared to the lower extremity. This is called "catching up" [71] and often is observed in the presence of lower extremity weakness or fatigue [72]. This creates increased loads in the distal muscles and joints [73].

The next goal is to properly time the lower and upper bodies. To accomplish this goal, it is necessary to have an optimal stride length (≥85% of the pitchers height). The length of a pitcher's stride allows enough time for the upper extremity and shoulder to get in the proper relative position [69]. The shoulder should be abducted between 70° and 90° and externally rotated between 60° and 90° at stride foot contact [53, 74, 75]. A short stride length results in the arm not having enough time to get into this proper position. This causes the shoulder muscles (deltoid and external rotators) to work quickly to get the arm in the proper position during late cocking. This can increase the torques at the shoulder and elbow. This is one reason the inverted "W" position at stride foot contact has been described as being problematic. Second, optimal stride length will allow a greater distance to apply force to the body with the stance leg, resulting in greater linear momentum. Lastly, optimal stride length will allow for pre-stretching (elastic energy storage) of the hip and core muscles. Commonly, baseball players have short stride lengths due to lower extremity weakness and/or tightness [56, 61]. With longer stride lengths, the mechanical moment arm for the knee is larger, therefore requiring greater torque production for both the hips and knee muscles at stride foot contact. If players have lower extremity weakness, they will stride short to minimize the mechanical moment arm. Baseball players also commonly present with hip flexor and hamstring tightness [76]. This tightness will mechanically restrict the athlete from having an optimal stride length. Stride length and stride foot contact position are very easy to measure on the field. Simply using the foot prints on the mound will allow measurement of stride length and foot position in reference to the driveline. As you can see, by optimizing stride length, many of the goals of this phase can be accomplished. The important part is identifying the cause of a sub-optimal stride length with clinical testing.

Hand position on the ball can have important effects on arm motion in early cocking. As the hands separate, the hand should be on top of the ball [77]. This allows optimum arm swing into maximum abduction/external rotation and minimizes the tendency to go into the "inverted W" position which increases stresses on the elbow. Also, extension of the wrists (the "prayer position") improves the efficiency of hand position and motion in late cocking.

Late Cocking

The late cocking phase starts when the stride foot contacts the ground and ends when the shoulder reaches maximal external rotation. The goals of this phase include lower extremity stiffness to absorb impact, pre-stretch of the abdominal muscles, proper positioning of the upper extremity, and pre-stretch of the shoulder internal rotators. During this phase the lower extremity energy production is mainly completed. At the start of late cocking, the stride foot contacts the ground and will create a large ground reaction force if the previous phase was performed optimally [54]. The entire lower extremity must prepare for this impact by co-contracting to maximize joint stiffness. If proper joint stiffness is not created at impact, momentum will cause the lower extremity to be eccentrically loaded, and all three joints will collapse into flexion [78]. This will be a source of energy loss and cause the upper body to compensate. It also has the potential to create balance deficits. This impact also stops the forward progression of the lower extremity allowing linear momentum to transfer to the upper body. Since a large portion of mass is removed from the equation, the resultant velocity of the upper body will be much larger.

After stride foot contact, the pelvis will rotate to face home plate, while the trunk remains rotated in the opposite direction. This creates what is known as "hip-trunk separation" [79, 80]. This allows for the pre-stretch of the abdominal muscles. Once pre-stretch occurs, a fast and explosive contraction of the abdominal muscles occurs causing trunk acceleration. This acceleration of the trunk will allow the shoulder to passively reach maximal external rotation. This is why the "inverted W" position, which positions the shoulder in internal rotation at lead leg contact, is not biomechanically optimal. It prevents trunk acceleration from passively externally rotating the shoulder. Therefore the shoulder external rotators will be forced to actively reach max external rotation and do so quickly. This increases shoulder and elbow torques. Another kinematic observation that occurs at this time is lateral trunk tilt toward the glove side. Lateral trunk tilt may occur to reduce the upper body's moment of inertia thereby allowing faster rotation. This is similar to figure skaters who bring their arms in tight to spin faster. This position has been demonstrated to be correlated with ball velocity [81].

Acceleration

The acceleration phase begins at maximum external rotation and ends at ball release. The single goal of this phase is maximal acceleration and velocity of the forearm. This is the fastest phase and is typically the phase that produces the largest valgus torque on the elbow. The shoulder should be in 90°–110° of abduction in the scapular plane (30° anterior to the frontal plane) [52, 53, 74]. The shoulder will often horizontally abduct out of the scapular plane if the stride foot lands to the glove side of the driveline during early cocking. This will place increased stress on the anterior shoulder and additional valgus stress on the elbow [82]. The elbow should also be in 90° of flexion to minimize valgus stress. If kinetic chain deficits exist prior to the acceleration phase, the body will attempt to compensate for the lost velocity by extending the elbow and increasing valgus torque.

Deceleration/Follow-Through

The deceleration/follow-through phase begins with ball release and ends with maximal internal rotation. The goal of this phase is to absorb the large amount of energy that was created throughout the previous phases of throwing. To accomplish this goal, the thrower should incorporate the full body, similar to the energy generation phases. Full range of motion is also very important at all joints. Having more motion and time to dissipate energy will decrease the force experienced at each joint. This relates to the equation for impulse momentum $Ft = (m_2v_2 - m_1v_1)$. It has been found in healthy throwers that the glenohumeral compression force is over 1000N (Fig. 1.1) during this phase [7, 10, 83]. That is near 1.5× bodyweight with large repetitions throughout a game and season. It has been shown that only 18% of the deceleration force can be related to shoulder/rotator cuff activity. Forty percent of the force is due to scapular muscle activity, and the rest is due to core/trunk eccentric activation [71, 84]. Increasing stride length can also help to reduce this compression force [57]. This likely occurs due to a larger follow-through step, allowing the lower extremity to absorb more energy. Decreases in clinical glenohumeral internal rotation can place more stress on the posterior shoulder.

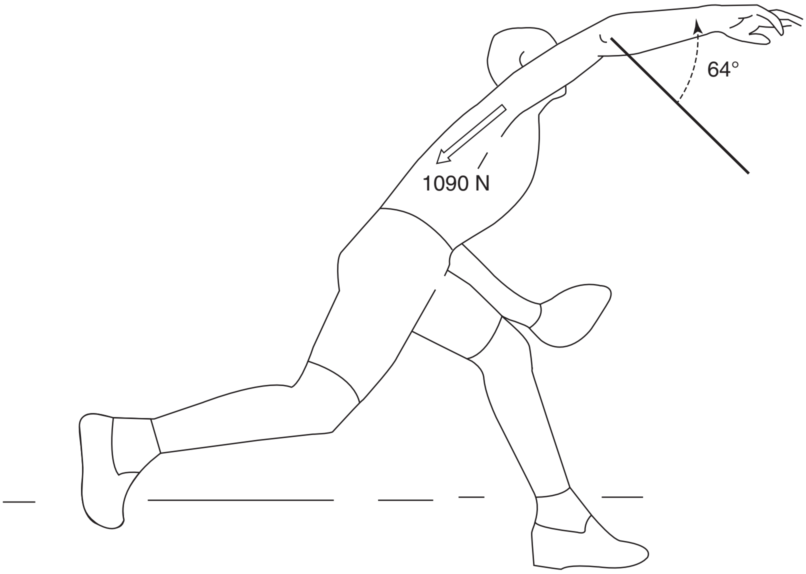

Fig. 1.1 This image demonstrates the instant of maximal compression force at the shoulder. This occurs during the deceleration/follow-through phase of pitching and is over 1000N of force. The posterior glenohumeral and scapular muscles are placed under eccentric load to decelerate the arm. (Reprint from Fleisig et al. [7], with permission from Sage)

Table 1.1 This contains the eight biomechanical nodes in baseball pitching to assess, normal and abnormal, the consequence and the clinical assessments to evaluate for dysfunction

	Node	Normal mechanics	Pathomechanics	Result	To be evaluated
1	Foot position	Directly toward home plate	Open or closed	Increased load on trunk or shoulder	Hip and/or trunk flexibility and strength
2	Knee motion	Stand tall	Increased knee flexion	Decreased force to arm	Hip and knee strength
3	Hip motion	Facing home plate	Rotation away from home plate	Increased load on shoulder and elbow	Hip and trunk strength
4	Trunk motion	Controlled lordosis	Hyperlordosis and back extension	Increased load on abdominals and "slow arm"	Hip and trunk strength
5	Scapular position	Retraction	Scapular dyskinesis	Increased internal and external impingement with increased load on rotator cuff muscles	Scapular strength and mobility
6	Shoulder/scapular motion	Scapulohumeral rhythm with arm motion (scapular retraction/humeral horizontal abduction/humeral external rotation)	Hyper angulation of humerus in relation lo glenoid	Increase load on anterior shoulder with potential internal impingement	Scapular and shoulder flexibility and strength
7	Elbow position	High elbow (above 90° abduction)	Dropped elbow (below 90 abduction)	Increased valgus load on elbow	Scapular position and strength, trunk and hip flexibility and strength
8	Hand position	On top of ball	Under or on side of ball	Increased valgus load on elbow	Shoulder and elbow position

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Having limited motion and therefore time to absorb energy will increase force and can lead to tissue adaptations. It has been demonstrated that players with less internal rotation from humeral retroversion have a thicker glenohumeral posterior capsule [85]. Maintaining full range of motion throughout the season and using the lower extremity to help absorb this large force should be considered to help mitigate these adaptive changes.

Attempts to establish observational methods to analyze the baseball pitching sequence as a unit have been difficult due to the rapid whole body motions. One method correlated body positions with optimum force production [77]. Another method characterized the sequence into nodes, body positions, and motions that correlate with optimal force production and minimal joint load [86, 87]. These observational analysis techniques can identify deficits in the sequence, which can be problematic, and could suggest the need to evaluate the musculoskeletal basis for the deficits (Table 1.1).

Tennis

Tennis places many individuals at risk for injury due to both the high repetition and the high loads on several joints [88–91]. The tennis serve has been identified as having the highest propensity for injury due to the explosive (high velocity and force) and repetitive nature. Therefore, the biomechanics of the tennis serve have been studied in detail to identify the phases that have potential for injury and the biomechanical flaws that can increase the likelihood for injury. Similar to baseball, the serve has been divided into five main phases (windup, early cocking, late cocking, acceleration, and follow-through).

Windup

The windup phase is the least stressful phase of the tennis serve; however, similar to baseball, it is very important. The goals of this phase are to (1) strategically position the body to generate force from the ground through the upper extremity and into the racket and to (2) apply the appropriate velocity vector on the ball for an accurate and consistent toss. The toss is very important for the overall success of the serve as the placement of the ball will determine the final velocity, spin, and trajectory. It can also play a role in the development of shoulder injuries. The windup starts with the ball (non-dominant hand) and the racket (dominant hand) in contact [92–94]. This phase ends at the instance the ball leaves the non-dominant hand. The location of ball contact on the racket is ultimately player preference, and there are no biomechanical differences between placing the ball against the strings and the throat of the racket. The ball and racket are commonly in front of the body with the majority of the player's body weight being placed on the front leg in a shoulder width apart stance. A right-handed player is often positioned toward the right net post. The trunk is often in a flexed position, further loading the front leg. As the ball and the racket separate, a large weight shift to the back leg will occur due to trunk extension and right trunk rotation. This initiates eccentric loading of the entire lower extremity, which will ultimately be used as stored elastic energy during the late cocking phase. The common deficits seen during the windup phase will be related to an insufficient weight shift that results in a reduced lower extremity involvement during the cocking phase [94–96].

Early Cocking

The early cocking phase is very important as the goals of this phase are (1) to create stored elastic energy through both legs (although the back leg often generates a larger ground reaction force due to the trunk position); (2) shift the center of mass posterior toward the racket and closer to the ground, which increases the range of motion to provide an acceleratory force; and (3) place the shoulder and racket in the proper position to transfer linear momentum. The early cocking phase starts with ball toss and ends with maximal knee flexion or squat depth. This phase is often referred to as the "trophy pose" since tennis trophies often model this position.

During this phase there are two preferred foot positions that players assume. The first is the foot-up position, which places both feet very close together. The second is the foot-back position, which assumes a shoulder width apart stance. Both techniques produce similar ball velocities; therefore there are no known performance advantages. There are also only subtle differences between the two techniques from a biomechanical perspective [92–94, 96]. For example, the foot-up technique typically requires a greater rear knee excursion, while foot-back requires greater front knee excursion [93, 94]. The foot-up technique also produces a higher vertical ground reaction force that correlates with larger angular velocities with the rear leg [96]. Either technique having lower maximal extremity strength is extremely important for producing powerful high-velocity serves. It has also been shown that the lack of lower extremity involvement will lead to slower racket velocities with no difference in the resulting upper extremity loads [90]. This is concerning as joint loads are higher per unit of velocity in players that don't incorporate the lower extremity [73].

Moving up the kinetic chain the pelvis starts to laterally tilt toward the racket side along with continued right trunk rotation, while the hips remain facing the net post (Fig. 1.2) [92–94, 96]. This allows additional elastic energy storage through the abdominal muscles (rectus and oblique). In addition, it is suggested to allow maximal angular momentum during the forward swing. The creation of hip-trunk separation is similar to baseball pitchers and maximizing this can increase serve velocity. Those with a weak hip/core often have difficulty with full-body functional movements similar to tennis serving [97].

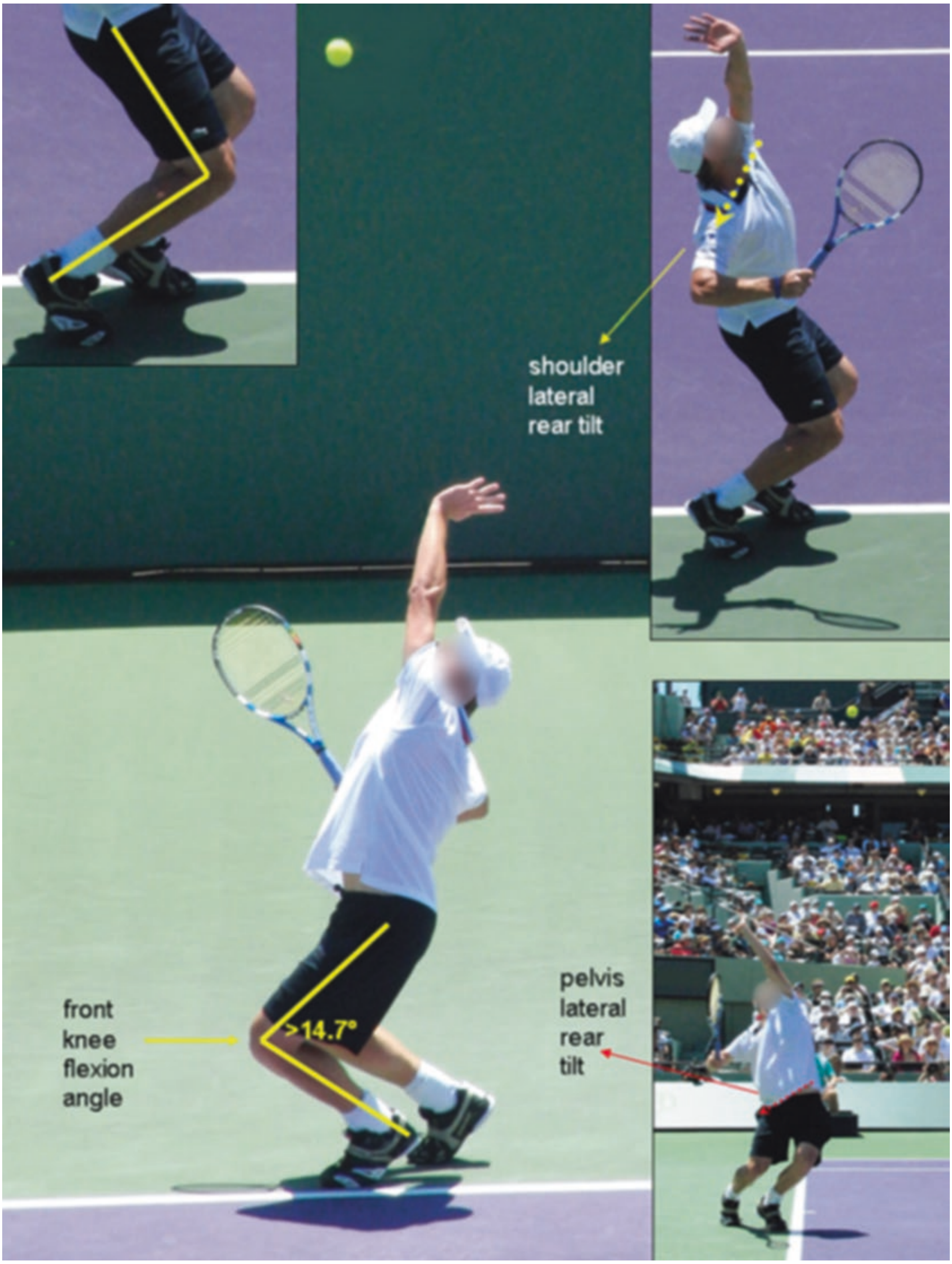

Fig. 1.2 The early cocking phase is represented from several different angles to demonstrate the various aspects of this phase. The front and rear leg kinematics are shown demonstrating significant knee and ankle motion. In addition, the lateral tilt of the pelvis and trunk is shown. (Reprinted from Kovacs and Ellenbecker [94], with permission from Sage)

Continuing to move proximally, the dominant shoulder begins to abduct (85°–100°), externally rotate, and horizontally abduct [92–94]. The amount of external rotation can be variable; however, close to 90° is desired to maximize the transfer of linear momentum from the rapid lower-body extension during the late cocking phase that creates the final position of maximal external rotation. Horizontal abduction often will end in the neutral position to create slight stored elastic energy through the anterior internal rotator muscles (pectoralis major and subscapularis). Weakness or fatigue of the deltoid and rotator cuff muscles can cause the shoulder to be in less abduction, external rotation, and horizontal abduction, thereby having detrimental effects when transitioning to the late cocking phase [91, 94, 95].

Late Cocking

The late cocking phase is considered to be the explosive lower extremity phase and the first aspect of the serve to create acceleration. The goals of this phase are to (1) generate vertical kinetic energy of the center of mass and (2) achieve maximal glenohumeral external rotation. This phase begins with maximal knee flexion and ends just before toe off. Once the lower extremity reaches the lowest position to create eccentric loading of the hips, knee, and ankle extensors, a stretch reflex will occur in those muscles (gluteus maximus, quadriceps, and gastrocnemius/soleus complex). The very fast stretch reflex will allow the stored elastic energy to be transferred into joint moments that create triple extension and therefore a very large vertical ground reaction force to accelerate the center of mass against gravity. This acceleration will transfer rotational momentum to the upper extremity causing passive maximal glenohumeral external rotation (175°–185° compared to the ground) with additional trunk extension [88, 93, 98]. This position is optimal to allow more motion to apply an acceleratory force on the racket during the acceleration phase. In addition, this position allows for maximal eccentric stretching of the large glenohumeral internal rotators and abdominal muscles of the trunk to produce an explosive stretch reflex. The lack of glenohumeral external rotation during the early cocking phase can cause the player to actively instead of passively reach this position and do so at a fast rate. Overtime this can be problematic as the external rotators (infraspinatus and teres minor) can be quickly fatigued [99, 100]. During max external rotation, the shoulder should also be positioned between 90° and 110° of abduction and 5° and 10° of horizontal adduction [93, 94, 96]. If additional external rotation is desired, the player will often compensate by horizontally abducting past neutral. However, this position is known to create internal impingement of the rotator cuff between the humeral head and the glenoid [101]. Over repeated serves, internal impingement can lead to undersurface rotator cuff tears [102]. The elbow is commonly between 92° and 115° of flexion with the radial/ulnar joint in neutral rotation and the wrist in extension with radial deviation [93, 94, 96]. Similar to the other joints, this creates eccentric stretch of the wrist flexors. This position is attempting to position the racket as low as possible, which is referred to as "racket drop" (Fig. 1.3). This allows the largest amount of motion to accelerate the racket.

Acceleration

The acceleration phase is referring to the acceleration of the racket toward the tennis ball. Although other phases of the tennis serve create large amounts of acceleration, this is the first point in which the racket begins its forward progression to the ball. The goal of this phase is to couple the acceleration of the trunk, shoulder, elbow, radial/ulnar, and wrist in a sequential order to create a building effect of rotational joint acceleration (similar to the physics of waves) that ultimately results in maximal racket velocity and therefore maximal serve velocity of the ball [93]. This phase starts at maximal external rotation and ends with ball contact. This phase has been shown to occur in under 1/100th of a second due to the explosive nature of the sequential muscular contractions [103]. These muscular contractions

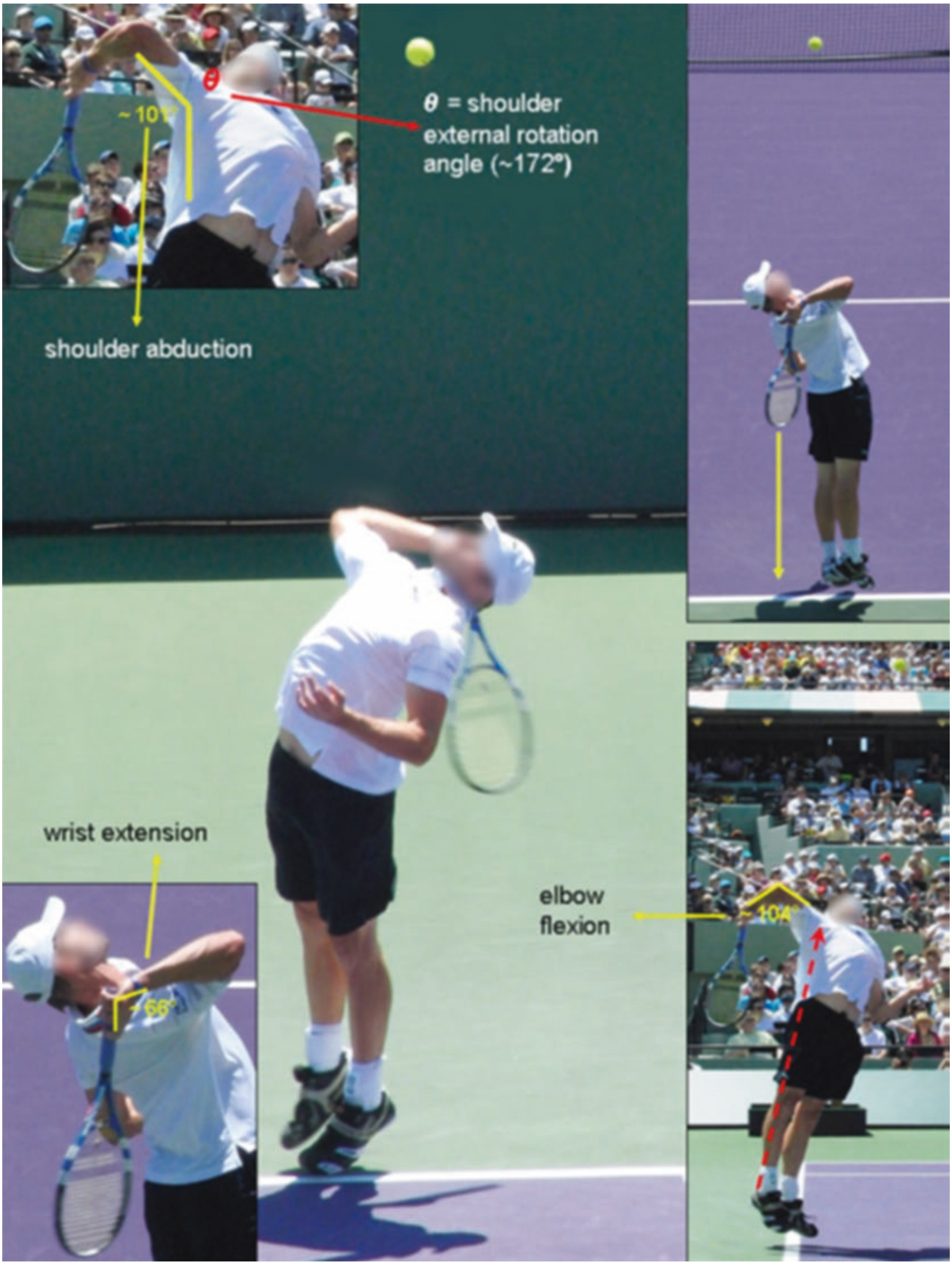

Fig. 1.3 The late cocking phase is represented from several different angles to demonstrate the various aspects of this phase. Maximal external rotation in the scapular plane occurs with the elbow in flexion and wrist in extension, creating the lowest vertical position of the racket. (Reprinted from Kovacs and Ellenbecker [94], with permission from Sage)

occur first in the abdominal muscles to create trunk flexion and left rotation. This is followed by activation of the serratus anterior to produce scapular protraction and stability [6, 104]. The massive glenohumeral internal rotators (pectoralis major, latissimus dorsi, teres major, and subscapularis) then contract followed by the wrist flexors and ulnar deviators. All of these contractions stem from a stretch reflex, which allow the transfer of elastic energy up the kinetic chain. The other factor that likely explains the continued building of acceleration is the reduction of mass from the lower extremity to the racket. According to Newton's acceleration law, $\text{angular acceleration} = \dfrac{\text{torque}}{\text{moment of inertia}}$, a decreased mass will reduce the moment of inertia, thereby increasing the angular acceleration of the next joint. Although alterations can occur in this phase, it is often thought that biomechanical deficits stem from previous phases. Failure of leg, core, or trunk muscle activation will increase the loads and muscle activation requirements in distal segments [71, 91].

Follow-Through

From a performance standpoint, the overall goal of the tennis serve is to generate maximal ball velocity. If the earlier phases of the serve are performed properly, that goal will be accomplished. Therefore, the follow-through phase often gets overlooked; however it has been shown to produce extremely large forces and torques [73, 90, 91]. Following the large amount of acceleration, there is a short period of time to decelerate and absorb that energy. Similar to the generation of energy during the prior phases, the player should be using the full kinetic chain to absorb this energy during the follow-through. Following ball contact the shoulder continues to violently internally rotate and horizontally adduct. The player will also start to flex at the trunk [73, 93, 94]. Therefore to absorb the initial amount of energy and begin the deceleration process, only the trunk and upper extremity are involved. This places large forces and torques on the lower back and posterior shoulder. The lower extremity, which contributed a very large aspect of the energy generation, does not play a role until the nondominant leg contacts the ground. This is a single leg landing which is often stiff (limited joint movement after impact). The trunk often will continue to flex, but following landing not much hip, knee, and ankle motion occur [96]. This is likely caused by having to quickly be in an athletic position to continue the match. The stiff landing over time can lead to increased stress on the anterior knee similar to basketball players and may develop into patellar tendinitis.

Similar to baseball, observational methods of analysis of the tennis serve sequence have been developed. A method based on kinematics breaks the serve into eight stages [94]. This analysis details success or failure of progression through the stages, but does not suggest reasons for success or failure, and does not correlate with performance. A kinetics-based method breaks the serve into eight nodes (individual segment position or motion) and one overall evaluation of the sequence [105]. It does suggest musculoskeletal reasons for failure and does correlate with performance (Table 1.2).

Table 1.2 This contains the eight biomechanical nodes in tennis serving to assess, normal and abnormal, the consequence and the clinical assessments to evaluate for dysfunction

	Node	Normal mechanics	Pathomechanics	Result	To be evaluated
1	Foot position	In line, foot back	Foot forward	Increased load on trunk or shoulder	Hip and/or trunk flexibility and strength
2	Knee motion	Knee flexion greater than 15°	Decreased knee flexion less than 15°	Increased load on anterior shoulder and medial elbow	Hip and knee strength
3	Hip motion	Counter-rotation with posterior hip tilt	No hip rotation or tilt	Increased load on shoulder and trunk, inability to push through increasing load on abdominals	Hip and trunk flexion flexibility and strength
4	Trunk motion	Controlled lordosis; X angle ~30	Hyperlordosis and back extension; X angle <30° (hypo). X-angle >30° (hyper)	Increased toad on abdominals and "slow arm"; increase load on anterior shoulder	Hip. Trunk, and shoulder flexibility
5	Scapular position	Retraction	Scapular dyskinesis	Increased internal and external impingement with increased load on rotator cuff muscles	Scapular strength and mobility
6	Shoulder/ scapular motion	Scapulohumeral rhythm with arm motion (scapular retraction/ humeral horizontal abduction/humeral external rotation)	Hyperangulation of humerus in relation to glenoid	Increase load on anterior shoulder with potential internal impingement	Scapular and shoulder strength and flexibility
7	Shoulder over shoulder	Back shoulder moving up and through the ball at impact. Then down into follow through	Back shoulder staying level	Increased load on abdominals	Front hip strength and flexibility, back hip weakness
8	Long axis rotation	Shoulder internal rotation/ forearm pronation	Decreased shoulder internal rotation	Increased load on medial elbow	Glenohumeral rotation

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Swimming

Compared to baseball and tennis, swimming mechanics are very unique for several reasons: (1) the swimmer accelerates from an interaction with the water, (2) the body experiences both gravity and buoyancy forces, (3) both arms are used repetitively, (4) there is no ground reaction force, and (5) the base of proximal stability is the core.

The swimming motion has been divided into two main phases: (1) pull-through and (2) recovery with further subdivisions for each phase. The pull-through phase consists of (1) hand entry, (2) early pull-through, and (3) late pull-through. The recovery phase consists of (1) early recovery, (2) late recovery, and (3) hand entry. Each of these phases will be discussed in detail.

Pull-Through

The pull-through phase of swimming is where a propulsion force is created to accelerate and pull the body through the water. This propulsion force is created by a combination of drag and lift forces, with the majority of the forward propulsion coming from drag between the upper extremity and the water [106, 107]. The lift forces likely reduce both surface and form drag of the body. These forces are created from the whole upper extremity moving through the water, but the hand is thought of as the major contributor [106, 108, 109]. The goals of this phase include (1) pushing water behind in a backward direction and (2) using as much cross-sectional area of the upper extremity to create propulsion. The first aspect of this phase is hand entry. The location the hand enters the water is very important. In the frontal plane, the hand should enter the water at shoulder width with the palm facing down [109–111]. A common alteration is that the hand enters the water too medial or even at times will cross over the midline of the body. This will cause the first pull motion of the upper extremity to be lateral instead of back toward the toes. This reduces propulsion force and creates wasted motions [106, 108, 109]. The other important feature of hand entry is the creation of what is called tilt angle. Tilt angle can be caused by (1) elevation of the scapula on the side of hand entry and contralateral scapula depression and/or (2) lateral trunk flexion [111]. This will allow a maximal reach at hand entry without placing the shoulder at risk for impingement [13]. A maximal reach is important for performance since it will allow a longer period of time to create propulsion force to accelerate the body. Often swimmers will attempt to increase their reach by forcing their shoulder into more abduction without optimal scapular upward rotation and lateral trunk flexion [13, 111]. This will place the humeral head in a position to contact against the acromion. This can also occur throughout a swimming event or over a season as the scapular upward rotators and core muscles fatigue due to overuse [112]. The last important aspect of hand entry is to maintain a high elbow position. At hand entry the elbow should remain high as it transitions into the early pull-through phase [111, 113]. At this position the high elbow is caused by glenohumeral abduction. Adequate motion and strength (deltoid and supraspinatus) and optimal scapular upward rotation and posterior tilt is necessary to obtain the high elbow position. These muscles can develop fatigue and long-term weakness which can cause the elbow to drop which will lead to the palm facing medial at hand entry [109]. Supraspinatus tendinitis is also a very common injury within swimmers, and the pain associated with this injury can also cause elbow drop [114].

Once hand entry has occurred, the swimmer will prepare for the early pull-through phase, which is otherwise known as the "catch." At hand entry the swimmer's palm is facing the bottom of the pool. To create the proper propulsion force, the swimmer needs to position the palm and forearm perpendicular to the surface of the water. The way this occurs is by maintaining the high elbow position and moving into glenohumeral internal rotation with elbow flexion [113]. This is the shortest and most efficient way to create that perpendicular position of the hand and forearm. This movement has been shown to mainly occur with both the pectoralis major and the subscapularis [110, 115]. At the start of the early pull, the body will go from its position of 20°–40° of body roll away from the pull-through shoulder back to neutral. This is mainly created by the strong pectoralis major contraction. Once again a very common error is dropping the elbow. If the subscapularis is weak or fatigued, then internal rotation of the shoulder is not effective causing the elbow to drop. This is very similar to the belly press examination test to assess the health of the subscapularis [116, 117]. When the elbow drops, the shoulder is placed in external rotation, not allowing the subscapularis to aid in propulsion. This also will shorten the pull and change the amount of time the hand is perpendicular to the water. The latissimus dorsi, teres major, and posterior deltoid will then take over early, pulling the humerus into extension. This can place increased demand on these muscles possibly leading to early fatigue. The elbow drop will also position the palm facing toward the midline instead of toward the toes. This will reduce the propulsion force created to accelerate the body forward during that pull [106, 108, 109]. The high elbow position should be maintained until the hand reaches chest level [13, 110]. Additional internal rotation beyond this point can place the shoulder in a position of subcoracoid impingement or anterior internal impingement [118, 119].

The next phase is the late pull-through or the "power stroke," since most of the swimmer's acceleration is generated in this portion of the pull. At this point the shoulder has internally rotated to chest level, and the palm is facing perpendicular to the surface of the water, creating a very large surface area and therefore creating maximal propulsion [109, 110]. At this point the swimmer maintains the amount of internal rotation while extending both the shoulder and the elbow at a high velocity. This has been shown to be accomplished by the latissimus dorsi, posterior deltoid, teres major, and the rotator cuff, with the exception of the infraspinatus [110, 115]. This has the potential to create large forces and torques at the shoulder joint since shoulder loads have been shown to exponentially increase with arm velocity in water compared to land [120]. It was also shown that as velocity increases the functionality of the shoulder muscles will trade joint stability for arm velocity generation [120]. This can lead to increased translations of the humeral head in addition to more stress on the passive structures of the shoulder joint like the capsule and supporting ligaments. This phase ends as the hand exits the water.

Recovery

The recovery phase is much faster than the pull-through phase (accounting for 40% of the total) [115, 121]. Since the arm is not interacting with the water, it can be quickly repositioned to pull-through the water again. Therefore the goals of this phase include the following: (1) to quickly cycle the hand in front of the body for hand entry and (2) keep the hand from contacting the water. The first aspect of this phase is early recovery. This starts as the hand exits the water. Two things need to occur synchronously: (1) body roll toward the recovery arm and (2) glenohumeral abduction. The combination of these movements allows for an increased vertical height of the elbow with respect to the surface of the water [13, 111]. The body roll itself is responsible for several things in addition to increasing the vertical height of the elbow. First, it will pre-stretch the pectoralis major muscle just prior to the catch on the pull-through side. This will cause a more powerful contraction during the catch and early pull. Next the body roll will allow the head to get into a position above the surface of the water to take a breath. Currently it is a standard technique for swimmers to breathe on both sides, as unilateral breathers have been suggested to develop shoulder pain on the breathing side. Although swimmers currently do often breathe bilaterally, they typically have a favored side. The breathing technique involves a combination of cervical rotation and lateral tilt [122]. From a coaching perspective, swimmers are told to “get their mouth to their armpit.” To perform this movement, a forceful contraction of the scalenes and the sternocleidomastoid occurs to reach this end-range position. Repetitively swimmers can develop limitations in cervical motion due to tightness of these muscles. Although it seems to be a rare diagnosis, this tightness has the potential to lead to thoracic outlet syndrome [123, 124]. Finally, the body roll will keep the recovery shoulder to remain in the scapular plane (30° anterior to the frontal plane). If body roll does not occur, the shoulder will be required to horizontally abduct to elevate the elbow above the water. This will stretch the anterior capsule and place the shoulder in a position for internal impingement [101, 102]. This can lead to anterior instability and undersurface rotator cuff tears. The reason seen for a lack of body roll is good core control and strength. One study demonstrated that the lateral movement of the buoyance force vector will contribute to body roll [125]; however a strong and coordinated core is required to control it. Core training has also been shown to improve swimming performance [126]. Body roll can also be viewed as reducing the requirements of the shoulder during recovery. In addition to allowing the shoulder to function in the scapular plane, the body roll also will allow the swimmer to maintain the high elbow position with the shoulder in neutral rotation [111]. This allows the arm to travel the shortest distance to reach arm entry. A dropped elbow is a common altered swimming motion and has been thought to be a sign of supraspinatus fatigue, weakness, or injury. A dropped elbow can have several consequences: (1) the fingers dragged across the water create more drag, (2) the shoulder moves into horizontal abduction to raise the elbow, and (3) the shoulder externally rotates early causing the arm to swing out laterally, which can slow down the recovery and alter sequencing between arms.

The final phase is late recovery. This phase starts when the glenohumeral joint is abducted to 90° and ends at hand entry. The start of this phase is the highest vertical point the elbow will reach, which is caused by a combination of body roll and glenohumeral abduction. At the start of this phase, it is important for the glenohumeral joint to begin externally rotating from a position of neutral rotation. Externally rotating at this point will clear the greater tuberosity (supraspinatus insertion site) from approximating under the anterior acromial arch [111]. This would be coupled with scapular external rotation and posterior tilt. External rotation during this phase will also get the hand horizontal to the surface of the water and prepare for hand entry as the glenohumeral joint continues to abduct to shoulder width and the elbow begins to extend. This upper extremity position will maximize stoke length to allow for a longer and efficient pull-through. The point of hand entry will likely be performed accurately by having a proper recovery phase. The main areas of concern for the recovery phase are pain, weakness, or fatigue which will force swimmers into compensatory positions.

Finally there are two important aspects of the swimming stroke that occur during the whole duration. First, the leg kick has often been thought to drastically increase the propulsion force of swimmers. Based on the force vectors created from the feet against the water, the leg kick likely has minimal contribution to the propulsion force [106, 127, 128]. However, it is likely that the leg kick contributes significantly to the lift force of the lower extremity which prevents the legs from sinking. As discussed previously the strong pull-through phase not only creates propulsion force but also upper body lift. When the upper body is lifted, it will create a torque at the center of mass which will force the lower extremity deeper into the water [106]. By keeping the legs on the top of the water with a strong kick, there will be less drag force and it will make the pull-through phase more efficient and effective. The mechanics of the legs are very important to maximize lift force without creating additional drag from the leg movement. There are two main aspects of the kick: (1) the down kick and (2) the up kick. The down kick should be initiated by a strong contraction of the hip flexors while the knee and ankles stay relaxed to create a whiplike effect in the water. The ankles will get forced by the water into an end range plantarflexion position (maximize lift) and will hold this position due to passive restraints. As the foot reaches its maximal downward displacement from the hip flexor contraction, the hip extensors will then contract to pull the leg back up with the knee slightly flexing and the ankle slightly dorsiflexing. This repositions the legs to repeat the down kick, and this cycle will help generate elastic energy through the lower extremity. The second and last important aspect that should occur throughout the swimming stroke is maintenance of proper head position. Since the head is the first aspect of the body colliding with the water, it is crucial to minimize form drag. Changes in head position will consistently change the interaction with the head and the water which can increase drag. Therefore it is important to maintain a neutral cervical spine position to reduce drag [129]. The head should look toward the bottom of the pool at all times except for breathing. Many swimmers will extend at the cervical spine to look out of the water either for their opponents or the wall. The head turn during breathing should minimize the surface area interacting with the water. This is performed by aiming toward the armpit instead of rotating directly to the side. Improper head and breathing technique can drastically increase drag and therefore performance.

Conclusion

In conclusion, regardless of the sport, the overhead motion is a complex interaction of full-body motor control that incorporates many biomechanical principles to optimize and enhance performance. Interestingly this is often completed without the conscious knowledge of the athlete and often times the clinician. This chapter attempted to illustrate the normal and abnormal movement strategies in baseball pitching, tennis serving, and freestyle swimming to help the clinician better treat these athletes.

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2

Pathomechanics and Injury in the Overhead Motion

Charles Thigpen and Duncan T. Evans

Introduction

The baseball pitch is one of the fastest recorded human movements, with each pitch placing stresses on the upper extremity that approach the biological limits of human tissue [1]. Since the early 1990s, researchers have been using high-speed cameras to capture pitching kinematics and then calculating pitching kinetics through the use of inverse dynamics. This requires access to expensive lab equipment and trained biomechanist, limiting the availability to those at the professional or elite level. However, recent advances in technology have led to more affordable and readily available means that clinicians can use to analyze throwing mechanics.

Pitching-related shoulder and elbow pain is prevalent ranging from 46% to 57% of pitchers [2]. There are several mechanical factors associated with increased arm stress and pitching-related arm injury. Interestingly, as pitch velocity has increased in the professional ranks, so has pitching-related injuries. As such, optimizing pitching mechanics that limit arm stress is one strategy to decrease injury risk. Given that most sports clinicians are caring for injured athletes, it is important to familiarize themselves with appropriate mechanics and be able to identify common mechanical tendencies associated with injury or increased stress on the shoulder and elbow.

This chapter will briefly review the "average" or normal mechanics and then contrast with pitching mechanics associated with injury or increased arm stress. These mechanics will then be linked to common impairments the clinician might consider evaluating to optimize pitching mechanics.

Normal Mechanics

Pitching is a highly complex motion requiring precision timing and coordination of multiple moving segments as kinetic energy is transmitted up the kinetic chain. The throwing motion is traditionally divided into six phases: windup, stride, cocking, acceleration, deceleration, and follow-through. Within each phase, there are certain events that are indicative of *good* mechanics – proper force generation through the lower half with appropriate timing and sequencing leading to an efficient transfer of energy through the kinetic chain to be transferred to the ball. This is governed by the summation of speed principle, which states that optimal energy transfer occurs

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when the subsequent segment initiates rotation as the previous segment reaches maximal angular velocity [3–5]. Under most circumstances, good pitching mechanics will improve pitching performance while limiting the extreme loads on the shoulder and elbow when compared to more extreme pathological mechanics.

Pathomechanics

As mentioned previously, a sound kinetic chain is paramount in good pitching mechanics. Any weak link in the kinetic chain can lead to a *catch-up phenomenon* in which energy is lost early in the throwing motion and thus distal segments are exposed to increased stresses in order to achieve the desired pitch velocity [6, 7]. Of note, it is important to distinguish the difference between *poor mechanics* and *pathomechanics.* Poor mechanics can be thought of as errors that contribute to reduced pitch effectiveness, whereas pathomechanics can be thought of as errors that contribute to reduced pitch efficiency or contribute to increased injury risk.

Windup: Normal Mechanics

The windup phase begins as the athlete then shifts their weight to the back leg and rises into a position of single-limb support on the drive (rear) leg and ends with hand separation. The pitcher should maintain good trunk control with his center of gravity (COG) over the drive leg, lifting the stride (lead) leg above 90° hip flexion to maximize production of potential energy [8]. Maintaining a level pelvis with good trunk control allows for generation of maximal momentum once forward motion is initiated with the stride hip. The drive leg should maintain slight knee flexion, and the pitcher should appear stable and balanced with his eyes focusing on the target. The hips, shoulders, and stride foot should all be in line with the target at the end of the windup phase.

Of note, the pitcher may choose to begin the throwing motion from the *stretch* position in order to hold runners on base. The stretch eliminates a high leg kick and allows for a faster delivery and thus less time for a runner to steal base. Despite the lack of a high leg kick, studies have shown no significant biomechanical differences in joint kinetics, kinematics, or pitch timing [9].

Clinical Assessment of Pitching Mechanics

Clinical assessment of pitching mechanics provides a useful adjunct to successful returning pitchers to sport. We have integrated the *A*ssessment of biome*C*hanical *E*fficiency *S*ystem (*ACES*) tool that is based on a systematic review of the literature identifying pitching mechanics associated with arm injury [10]. The 20 items are divided into key moments in pitching of windup, stride, stride foot contact, arm cocking, acceleration, deceleration, and follow-through (Fig. 2.1). We recommend 3–5 on-target fastballs to be scored using software such as Dartfish™. Each item is scored as 0 (no error) or 1 (error), and then items are summed where a higher score indicated more pitching mechanical characteristics associated with increased arm stress and/or injury.

Total ACES efficiency scores tend to range from 2 to 12 and have demonstrated acceptable intrarater and interrater reliability. In adolescent pitchers, seven items (knee height during windup, hand separation and position, stride length, arm position at max cocking, and arm slot and trunk flexion during follow-through) explained 89% of the variability in the total score. This tool is integrated throughout each phase as a tool to assess pitching mechanics.

Windup: Key Indicators of Good Mechanics

In the windup, special attention should be paid to the lower kinetic chain at the critical point of peak knee height (stride leg). From a lateral view, the pitcher should be in a tall position with the COG maintained over the drive leg and the pelvis level. From an anterior view, peak knee height should be <90°. As the pitcher travels down the mound toward home, the stride leg hip should be pushed downhill with the trunk maintaining their COG over their stance leg and level shoulders.

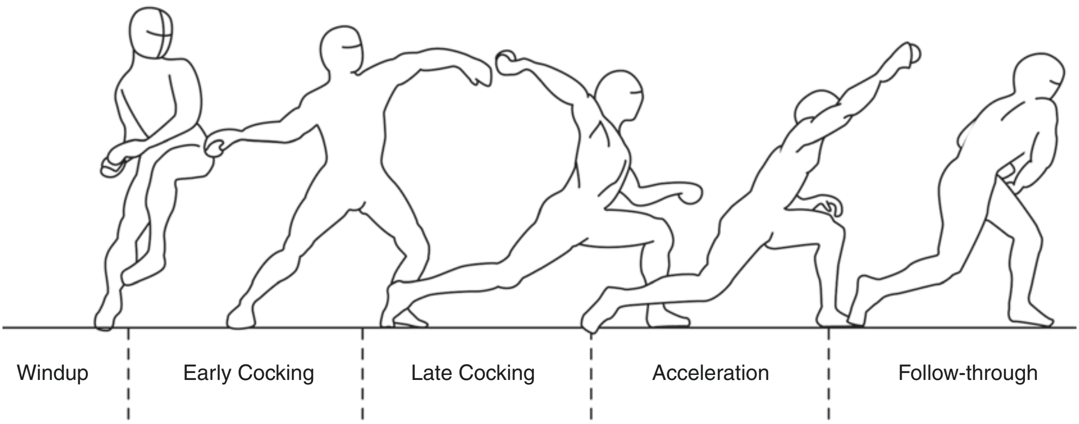


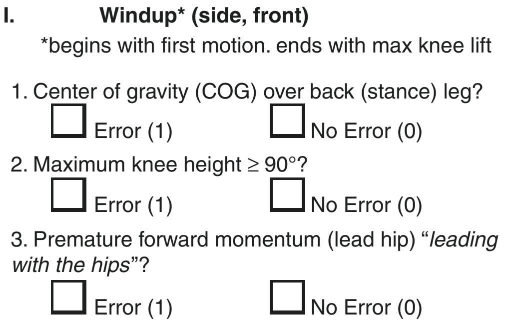
Fig. 2.1 The classically described five phases of pitching reflecting the key timepoints within which to assess and reference pitching mechanics

Windup: Pathomechanics

The most common flaws in the windup phase result from poor hip and core control at the point of peak knee height during single-limb support. This manifests primarily in three different ways: the pitcher falling into a Trendelenburg stance, the pitcher assuming a posterior trunk lean over the drive leg, or the pitcher prematurely initiating forward momentum toward the target. Observation of any of these errors is indicative of an unstable base of support (BOS). Failure to achieve a stable BOS during the windup results in significant loss of kinetic energy from the lower extremities and requires greater demand from the distal segments in order to achieve desired pitch velocity [11, 12].

Clinical Assessment of Mechanics

Windup is reviewed from the first motion until maximum lead knee lift. The pitcher should maintain their center of gravity over their stance leg then lift their lead leg no higher than 90° as they begin forward motion down the mound. Tilting of the trunk toward the second base or leading with the lead hip beyond should begin with the stance leg and not with the hips or front side "falling down" the slope of the mound. Each of these items is scored as below (Fig. 2.2).


I. Windup* (side, front)
*begins with first motion. ends with max knee lift

1. Center of gravity (COG) over back (stance) leg?
☐ Error (1) ☐ No Error (0)
2. Maximum knee height ≥ 90°?
☐ Error (1) ☐ No Error (0)
3. Premature forward momentum (lead hip) "*leading with the hips*"?
☐ Error (1) ☐ No Error (0)

Fig. 2.2 Windup

Clinical Pearl: Linking Impairments to Mechanics

Failure to obtain a stable balance point may be indicative of stance leg weak hip abductors or limited ankle mobility. Consider overhead squat assessment and side planks as simple assessments to quickly identify physical limitations or impairments.

Stride: Normal Mechanics

The stride phase begins with hand separation and ends at the point of stride foot contact (SFC). Upon initiation, the pitcher's COG is lowered as the stride leg is extended in the frontal plane toward the home plate in synchrony with the glove-side arm [8]. Drive leg hip and knee extension push the pelvis toward the target with the trunk lagging behind to maintain COG over the drive leg. The stride leg hip externally rotates, while the drive leg hip internally rotates, opening the pelvis to face the target [8, 11]. The stride foot should make contact with the mound in a heel-to-toe pattern with the knee flexed.

In the upper body, the throwing hand is separated from the glove hand with the throwing hand in a pronated, *hand-on-top* position [13]. The pitcher should maintain the same angle of elbow flexion in both the throwing arm and the glove-side arm, so that they appear to be mirror opposites of one another. This serves to preserve balance throughout the delivery as the shoulder moves into a position of external rotation and horizontal abduction [14].

Stride: Key Indicators of Good Mechanics

The stride should be examined from a lateral view. As the hands separate, the pitcher should maintain hand position on top of the ball with the forearm pronated [13]. The arms should horizontally abduct in synchrony with the forward-moving stride leg, and the glove-side arm should maintain a high position so that it mirrors the pitching arm. Just prior to SFC, the stance leg should be in a position of internal rotation, while the stride leg is externally rotated, preparing the pelvis for maximal angular velocity. In terms of timing, the entire stride phase (from initiation of forward movement to SFC) should be less than 0.95–1.05 seconds [14].

Stride Foot Contact: Key Indicators of Good Mechanics

The point of SFC should be critically examined, as this point marks the beginning of energy transfer from the lower kinetic chain to the upper kinetic chain. A lateral view should be examined first. The total stride length should be roughly 75–85% [83 ± 4%] of body height with the lead knee in 45 ± 9° flexion [15, 16]. It is important to note that youth pitchers will typically show lower values of knee flexion at SFC, and a stride length of 65–85% total body height is acceptable for younger pitchers. The throwing elbow is flexed with the shoulder abducted ~90° and externally rotated to approximately 60° [16].

From an anterior view, the stride foot should be in line with both the stance foot and home plate with the angle of the stride foot being slightly closed (pointed toward third base for a right-handed pitcher). Attention should then be paid to the position of the trunk and throwing arm. The trunk should remain closed and the throwing arm semi-cocked in the 1 o'clock to 2 o'clock position. The glove-side arm should be high with a closed lead shoulder, indicating that trunk rotation has not yet begun.

Stride: Pathomechanics

A stride length <75% body height and a stride duration >1.05 seconds are both indicative of a poor "push" off the rubber or minimal force production through the lower kinetic chain. House and Thorburn have suggested that a pitcher has approximately 1 second (0.95–1.05 sec) to get from first forward movement in windup to SFC [14]. If the initial phases of throwing are not completed within <1.05 seconds, subsequent events after SFC are likely to fall out of sequence, resulting in decreased performance and increased injury risk.

In the upper extremity, failure to maintain a "hand-on-top" position will lead to delayed glenohumeral abduction and early external rotation, causing the pitcher to be "late" in his delivery [13]. The delay in delivery is associated with arm hyperangulation and is associated with poor pitch accuracy (unable to hit arm side down or glove side away and up) as well as increased medial elbow valgus load.

Stride Foot Contact: Pathomechanics

Improper stride foot placement may compromise both pitch effectiveness and efficiency. Excessively "closed" stride foot positions may affect accuracy by forcing the pitcher to throw across the body, while an excessively "open" foot position may place increased demands on the abdominal muscles, anterior shoulder complex, and medial elbow [6].

Stride knee flexion angle has been shown to correlate with shoulder and elbow torques [9]. Many authors have speculated that stride knee flexion increases as a pitcher ages as an adaptive mechanism for continued high-velocity pitching [17].

Early trunk rotation, known as *opening up*, is a common error that leads to suboptimal utilization of the stretch-shortening cycle (SSC) through the obliques and thus greater stresses on the distal kinetic chain and increased HIRT [16]. Improper sequencing or timing of the hips and trunk will also have detrimental effects on pitch velocity and command.

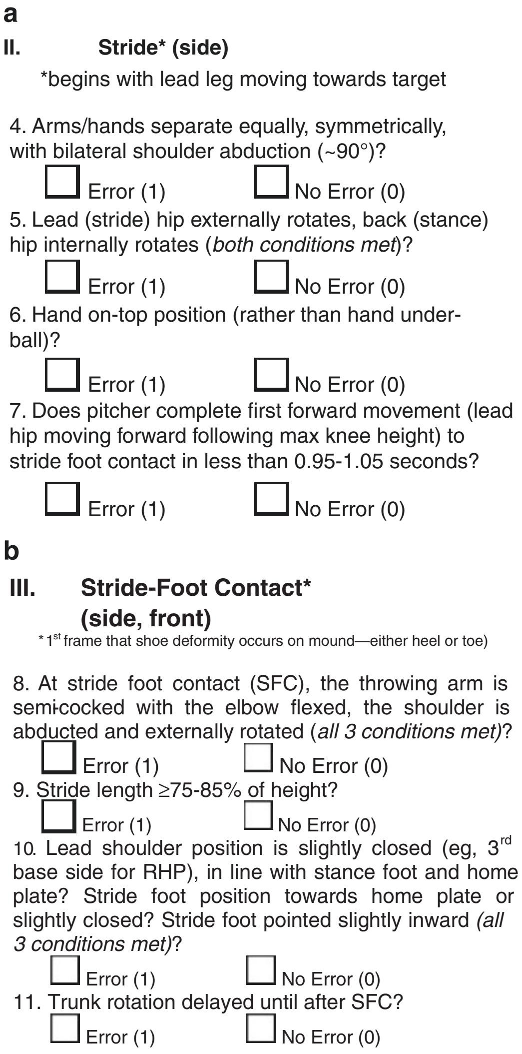
Special attention to the early phases of throwing are important as the windup and stride phases are the most crucial for identifying and addressing mechanical flaws. Errors in these two phases will disrupt appropriate pitching timing, are the most detrimental to pitch efficiency, and can lead to the greatest amounts of stress being placed on the throwing arm. Fortunately, these errors are the most identifiable allowing for correction early in the pitch cycle often eliminating errors later in the delivery.

Clinical Assessment of Mechanics

The key items are broken down for the stride phase below during the stride phase and at stride foot contact (Fig. 2.3).

Clinical Pearl: Linking Impairments to Mechanics

Reduced stride length can be due to soft tissue restriction in the stride leg hamstrings and the stance leg hip flexors and rotators. Observation of "opening up" too early could be due to limited hip internal rotation on the drive leg, whereas a too closed stride foot could be due to limited hip external rotation of the stride leg [6].



a

II. Stride* (side)

*begins with lead leg moving towards target

4. Arms/hands separate equally, symmetrically, with bilateral shoulder abduction (~90°)?

☐ Error (1) ☐ No Error (0)

5. Lead (stride) hip externally rotates, back (stance) hip internally rotates (*both conditions met*)?

☐ Error (1) ☐ No Error (0)

6. Hand on-top position (rather than hand under-ball)?

☐ Error (1) ☐ No Error (0)

7. Does pitcher complete first forward movement (lead hip moving forward following max knee height) to stride foot contact in less than 0.95-1.05 seconds?

☐ Error (1) ☐ No Error (0)

b

III. Stride-Foot Contact* (side, front)

* 1st frame that shoe deformity occurs on mound—either heel or toe)

8. At stride foot contact (SFC), the throwing arm is semi-cocked with the elbow flexed, the shoulder is abducted and externally rotated (*all 3 conditions met)*?

☐ Error (1) ☐ No Error (0)

9. Stride length ≥75-85% of height?

☐ Error (1) ☐ No Error (0)

10. Lead shoulder position is slightly closed (eg, 3rd base side for RHP), in line with stance foot and home plate? Stride foot position towards home plate or slightly closed? Stride foot pointed slightly inward *(all 3 conditions met)*?

☐ Error (1) ☐ No Error (0)

11. Trunk rotation delayed until after SFC?

☐ Error (1) ☐ No Error (0)

Fig. 2.3 (**a**) Stride. (**b**) Stride- foot contact

Arm Cocking: Normal Mechanics

The cocking phase begins with SFC and ends at the point of maximal shoulder external rotation (late cocking). Once the stride foot is rooted firmly into the ground, angular pelvic rotation increases to velocities exceeding 400° per second, followed quickly by lumbar spine hyperextension and upper trunk rotation [1, 9, 11]. The practice of delaying upper trunk rotation ensures that the hips have rotated far enough to generate adequate hip-shoulder separation, which is thought to be responsible for up to 80% of ball velocity during the pitching cycle. Elite pitchers typically generate 40–60° of hip-shoulder separation [14]. As the upper trunk extends and rotates to face the target, the elbow and hand lag behind the body as the shoulder moves into the critical position of maximal external rotation (150–180°) and horizontal adduction (10–20°) known as "late cocking" [11]. The critical point of late cocking is associated with the highest loads on the medial elbow. The elbow is flexed to 90–95° with the forearm maintaining a hand-on-top grip. The scapula is in a position of maximal retraction, lateral rotation, and posterior tilt [8].

During this phase, pitchers intuitively lean to their glove side, a strategy known as *contralateral trunk lean* (CTL). Peak CTL occurs between the peak elbow varus moment and max external rotation, with a mean value of 24° ± 10° [18–20]. The concept of increased CTL and injury risk versus performance benefits is discussed in-depth later in this chapter.

Arm Cocking: Key Indicators of Good Mechanics

From an anterior view, the clinician should be able to view the pelvis rotating prior to trunk rotation. Contralateral trunk tilt should fall within the established acceptable ranges of 14–34°, and the elbow should remain above shoulder level. From the lateral view, attention should be paid to hand position at early cocking and maximal external rotation at late cocking. The hand should maintain an "on-top" position at initiation of cocking, with the shoulder reaching a max ER value between 150 and 180° (measured from the horizontal) in late cocking.

Arm Cocking: Pathomechanics

Contralateral trunk tilt (CLT) is a concept that has recently received increased attention. Oyama et al. found that pitchers who show larger CLT angles demonstrate significant increases in ball velocity but at the cost of increased shoulder and elbow joint moments [18]. Solomito further investigated CLT in a cohort of 99 college baseball pitchers. Their findings showed that for every 10° increase over the mean CLT (24°) at the point of max ER, ball velocity increased by 1.5% (1.1 mph, $P = 0.003$). However, this increased velocity was associated with a 3.2% increase in glenohumeral internal rotation moment (2.5 Nm, $P < 0.001$) and a 4.8% increase in elbow varus moment (3.7 Nm, $P < 0.001$) – demonstrating that CLT affects joint moments at a greater extent than it does ball velocity [20].

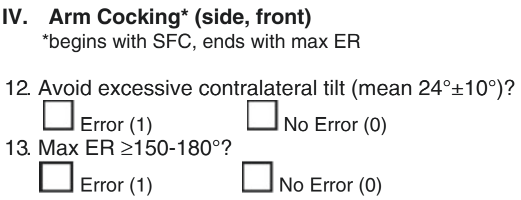
Viewing the pitcher from a lateral perspective, insufficient shoulder ER at late cocking (<150°) will lead to a drop in ball velocity while also putting the medial elbow at increased risk [11]. A pitcher who shows <150° of max ER should be thoroughly assessed to identify impairments in soft tissue extensibility and joint arthrokinematics that may be contributing to this.

Clinical Assessment of Mechanics

The pitcher should maintain a relatively level pelvis and shoulders during arm cocking and achieve sufficient external rotation as compared to hyperangulation as defined below (Fig. 2.4).

Clinical Pearl: Linking Impairments to Mechanics

External rotation deficits often result if difficulties reach an acceptable range of maximal shoulder external rotation in late cocking. Potential soft tissue restrictions in the pectoralis major/



IV. Arm Cocking* (side, front)
*begins with SFC, ends with max ER

12. Avoid excessive contralateral tilt (mean 24°±10°)?
☐ Error (1) ☐ No Error (0)
13. Max ER ≥150-180°?
☐ Error (1) ☐ No Error (0)

Fig. 2.4 Arm cocking

minor, latissimus dorsi, teres minor, and subscapularis should be evaluated. Rarely, are glenohumeral joint glide deficits associated with decreased shoulder external rotation in a thrower.

Acceleration: Normal Mechanics

The acceleration phase occurs between the points of maximal shoulder external rotation and ball release. During this phase, the shoulder moves from a position of maximal external rotation to internal rotation, as kinetic energy is transferred from the core and trunk into the arm in a *whiplike* fashion. The stride leg hip flexes as the trunk transitions from its hyperextended position to a position of trunk flexion (mean trunk flexion = 32–55° at ball release). The stride leg knee maintains flexion initially and then extends to roughly 58° at the point of ball release. The throwing shoulder maintains a position of ~90° abduction as the elbow extends rapidly from 90 to 120° flexion at late cocking to ~25° just prior to ball release [21].

Acceleration: Key Indicators of Good Mechanics

The lateral view will provide the most information regarding proper acceleration mechanics. Key criteria to examine include stride knee excursion from start to finish, maintaining a high elbow position throughout, and forward trunk tilt at ball release. For knee excursion, there is no clear "range" of acceptable values. However, it should be apparent that the stride knee moves from a position of flexion initially to a more extended position at ball release. A 5–10° change in angle is typically observed. The throwing arm should remain abducted >90° with the elbow higher than the shoulder.

Acceleration: Pathomechanics

Flaws during acceleration include inadequate trunk flexion as well as poor knee excursion moving from flexion into extension at the point of ball release. Both of these indicate poor linkage of the kinetic chain in transferring force from the lower half to the ball. Attention should also be paid to the position of the elbow during the acceleration phase, as an arm abduction angle of <90° will result in significantly increased loads at the elbow (Aguinaldo and Chambers 2009).

Clinical Assessment of Mechanics

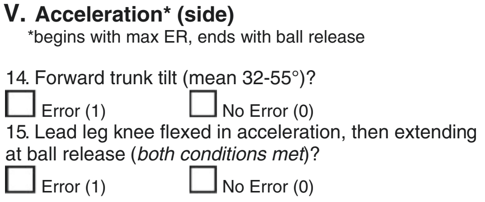
Acceleration following maximum arm cocking is characterized by sufficient forward trunk tilt with lead knee flexion until ball release as scored below (Fig. 2.5).

Clinical Pearl: Linking Impairments to Mechanics

Observation of the elbow dropping below 90° may be due to deficits in posterior shoulder chain muscle performance but can also be due to tightness in the latissimus dorsi and teres major musculature. Additionally, lack of knee excursion may be due to poor quadriceps strength (i.e., observation of a "stiff" stride leg) or lack of hamstring extensibility (i.e., failure for knee to extend as ball is released) on the stride leg.

Deceleration: Normal Mechanics

The deceleration and follow-through phases are most critical in force dissipation. Deceleration begins with ball release and ends with the shoulder in a position of maximal internal rotation. The trunk and hips continue to flex as the COG is propelled over the extending stride leg

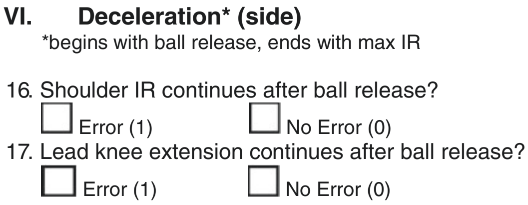


V. Acceleration* (side)
*begins with max ER, ends with ball release

14. Forward trunk tilt (mean 32-55°)?
☐ Error (1) ☐ No Error (0)
15. Lead leg knee flexed in acceleration, then extending at ball release (*both conditions met*)?
☐ Error (1) ☐ No Error (0)

Fig. 2.5 Acceleration

knee. The throwing elbow continues to extend as the shoulder internally rotates and horizontally adducts across the body to 35° [21]. The scapula de-rotates from an upward position, returning to an anteriorly tilted posture [6]. This phase is associated with high loads at the glenohumeral joint, with distraction forces reaching 80–100% body weight [22–24].



VI. Deceleration* (side)
*begins with ball release, ends with max IR

16. Shoulder IR continues after ball release?
☐ Error (1) ☐ No Error (0)
17. Lead knee extension continues after ball release?
☐ Error (1) ☐ No Error (0)

Fig. 2.6 Deceleration

Deceleration: Key Indicators of Good Mechanics

The back should be flat with the pitcher in a balanced position on the stride leg. Less maximum lead knee flexion angular velocity, increased knee extension (~58° mean knee extension), and knee extension angular velocity at ball release are all associated with increased ball velocity [21] [11].

Deceleration: Pathomechanics

Pathological findings during the deceleration phase include failure of the shoulder to continue internally rotating and failure of the stride leg knee to continue extending after the point of ball release. These both would indicate poor dissipation of the large amounts of kinetic energy that are transmitted to the throwing arm during the acceleration phase and lead to increased stresses placed on the posterior shoulder tissues.

Clinical Assessment of Mechanics

Deceleration is characterized by continued shoulder internal rotation and lead knee extension after ball release allowing for dissipation of energy from the arm (Fig. 2.6).

Clinical Pearl: Linking Impairments to Mechanics

Failure to achieve maximal shoulder internal rotation can be due to posterior shoulder tightness which may include rotator cuff musculature and occasionally capsular restrictions in the mature thrower. Symmetry of total arc and cross-body motion should be assessed as well as humeral torsion using diagnostic ultrasound to understand normal ROM if recalcitrant to stretching and manual therapy. Observation of a stiff, flexed knee which does not continue extending after ball release should lead the clinician to examine hamstring flexibility and extensibility. This may also be the result of over striding.

Follow-through: Normal Mechanics

Follow-through begins at maximal shoulder internal rotation and ends with the pitcher in a fielding position. The trunk is fully flexed with the back flat and parallel to the ground. COG is maintained over a stable stride leg with the pelvis laterally rotating over a fixed femur and the knee in a position of near full extension. The throwing shoulder continues to horizontally adduct to 60°, allowing most of the remaining kinetic energy to be dissipated by the stride leg and core [6]. The drive leg is then brought to the ground without crossing over the stride leg and the pitcher assumes a defensive fielding position.

Follow-through: Key Indicators of Good Mechanics

Balance and posture are both keys throughout the entire pitching delivery but should be most apparent in the windup and follow-through phases when the pitcher is required to assume a position of single-limb support. Pitchers should choose to throw with either a ¾ or "over the top" arm slot, as this results in significantly less elbow varus torque when compared to a sidearm arm slot [25]. Subjectively, a long arc of deceleration should be observed from the throwing arm, trunk flexion, and lead knee extension, allowing for energy absorption in the trunk and legs and reducing stress placed on the throwing arm by transferring most of the weight and momentum of the body to the lead leg [11].

Follow-through: Pathomechanics

Pathological findings during the follow-through phase indicate disruption of optimal force transfer to the stride leg, thus causing the remaining kinetic energy to be absorbed by the throwing shoulder. Early in follow-through, observation of a flexed trunk that is not parallel to the ground, a pelvis that is adducted over the stance leg rather than laterally rotated, and/or valgus collapse/excessive flexion at the stride leg knee all indicate break down of in the kinetic chain resulting in inefficient force transfer as well as local overloading of the tissues.

A rather common pathological finding during late follow-through involves the pitcher abruptly stopping the throwing arm motion and "snapping back" before maximal horizontal adduction is reached, thus shortening the optimal "long arc" of deceleration. This greatly increases the stresses placed on the throwing arm as it eliminates the ability of the trunk and legs to dissipate force [8, 11].

Lastly, the forward momentum of the body should carry the pitcher toward home plate as the pitcher returns to double-limb support. For a right-handed pitcher, errors here may present as the right foot crossing in front of the left foot or the pitcher falling toward the first baseline during his follow-through.

Clinical Assessment of Mechanics

Follow-through is characterized by continued arm deceleration as the arm crosses the body and trunk flexes and is scored as below (Fig. 2.7).

VII. Follow-through*(side, front)
*begins with max IR, ends with arm across body

18. Arm crosses body diagonally, without sidearm or submarining?
☐ Error (1) ☐ No Error (0)
19. Trunk flexes forward?
☐ Error (1) ☐ No Error (0)

Fig. 2.7 Follow-through

Clinical Pearl: Linking Impairments to Mechanics

Observation of a rounded lower back should cue the clinician to examine stride leg hamstring length. Lack of a stable stride leg in follow-through can often be attributed to eccentric control of the hip abductors and deep rotators as well as weakness of the foot intrinsics and/or poor lateral ankle stability. Observation of "snapping back" and not finishing the follow-through is most commonly attributed to lack of stride leg hip internal rotation and/or hip extension but can also be linked to deficits in posterior rotator cuff muscle performance and flexibility.

Handedness Considerations: Righties Versus Lefties

Recently, Diffendaffer et al. showed that four kinematic variables were different between the right- and left-handers. At the point of SFC, left-handed pitchers demonstrated a more "open" position of the stride foot by roughly 4 cm with ~5° less hip-shoulder separation compared to their right-handed counterparts. They also showed 3° less maximal external shoulder rotation during cocking and had 2° less forward trunk tilt at the point of ball release [26]. No differences were seen in any kinetic variables. When analyzing throwing mechanics, it is important for the clinician to have an understanding of the subtle differences between right-handed and left-handed pitchers, as the inherit mechanical differences between the two are not necessarily indicative of pathological mechanics.

Pitching Surface: Flat Ground Versus Mound

Generally speaking, as flat ground throwing distance increases, pitchers exhibit changes in kinematics including a more open foot position and more upward trunk tilt at SFC with less trunk flexion and front knee flexion at ball release [27]. When examining kinetics, loads on the shoulder and elbow are similar when comparing pitching from a mound to throwing on flat ground at distances of <120′. However, throws at 180′ and beyond produced significantly greater elbow varus torque and shoulder internal rotation torque compared to distances of 120′ or less [28, 29]. Adolescent pitchers who displayed greater peak elbow extension velocity was higher in the mound condition but otherwise observed no differences.

Mechanical Trade-Offs: Performance Versus Injury Risk

Great controversy exists if there is a pitching performance versus arm injury risk trade-off when pitching. Given the complexity of pitching extrinsic factors such as game conditions and leveraged outings, prior pitching in the context of intrinsic physical capacity limits direct cause and effect of pitching mechanics associated with injury and high arm stress. However, a few important observations should be considered. Elite pitchers have been shown to *lead with the hips*, pushing the lead hip downhill while continuing to maintain the COG over the stance leg resulting in higher humeral internal rotation torque (HIRT) and higher elbow valgus load (EVL). However, these same mechanics result in and lower pitching efficiency in adolescent pitchers [13].

During stride, the hand-on-top position has been associated with lower HIRT, lower EVL, and higher pitching efficiency. Not maintaining hand-on-top position may lead to the throwing arm being "late" in the delivery, thus presenting issues with both increased arm stress and poor pitch command. Furthermore, maintaining this hand-on-top position while also keeping the lead shoulder closed has been shown to lead to even lower stresses at the shoulder and elbow and greater pitch efficiency.

Traditionally, an 11–5 or 1–7 arm ("over the top" or "overhand") slot is preferred, as a higher release point creates a more downward ball path and results in higher ground ball rates with lower arm stress.

Assessment and Clinical Application

Critical moments in a pitcher's delivery can take place in 1/250th–1/1750th of a second [14]. The human eye is only capable of processing images at a rate of 32 frames per second (FPS); therefore, assessment of pitching mechanics with the naked eye is an imperfect exercise and is not recommended for clinical practice. With advances in modern technology, there are a number of tools the clinician can utilize to help analyze throwing and pitching mechanics. Below you will find a brief review of some of the more popular methods for assessing mechanics.

3D Assessment

Classically, 3D motion capture has been the gold standard of motion analysis, and the baseball throwing motion has been studied extensively. This is traditionally performed in an indoor laboratory setting using expensive biomechanical equipment: (1) multiple (e.g., 6–12) high-speed, light-sensitive cameras, with frame rates ranging from 200 to 1000 FPS; (2) reflective markers that are tracked by the camera system; (3) real-time 3D digitizing which is required for quantitative analysis; and (4) force plates embedded in the floor or pitching mound [30].

Reflective markers are placed over the bony prominences on the bare skin of subjects. 3D movement space coordinates are reconstructed from the video images, and kinematic and kinetic are generated from 3D motion analysis. As stated earlier, access to 3D motion analysis has traditionally been limited to elite athletes or those undergoing complex biomechanical studies for an expensive fee (500–100 USD per assessment).

2D Assessment: Dartfish™

In contrast to 3D assessment, 2D video analysis is relatively inexpensive and appears to provide an effective means for coaches, players, and sports medicine providers to record and analyze the throwing motion. The popularity of smartphones and high-definition camcorders (e.g., GoPro) has drastically increased accessibility to high-speed hardware and software platforms for capturing and analyzing the throwing motion. Some of the newer models of smartphones are capable of capturing footage at frame rates of 240 FPS (Apple iPhone X).

Many 2D video applications are free to use and allow the clinician to record video and analyze multiple videos side by side at a frame-by-frame rate directly on the recording device. The more advanced applications will allow video to be uploaded to Internet-based software platforms for further analysis and can offer the ability to sync up to eight different cameras depending on the package purchased. While not as advanced as 3D motion capture, the use of these 2D applications will allow for crude calculation of joint angles, distances (e.g., stride length), and biomechanical timing (e.g., first forward movement to foot strike).

Several studies have assessed the overall utility of 2D video analysis in evaluating pitching mechanics [13, 31]. From the body of research, it is apparent that 2D video analysis is a valid tool that can be utilized clinically for the purposes of identifying and correcting pathomechanical flaws in a pitcher's delivery. However, caution should be used in the comparison to 3D normative data, and careful attention should be given to the process of obtaining the assessment to be used [30]. At a minimum, both a lateral view and an anterior view should be obtained for ~5 pitches at max effort. If able to obtain a view from directly above the pitcher, this may also be useful – but not necessary.

2D Video Versus 3D Motion Analysis: Pros and Cons

2D video analysis is an attractive alternative to 3D motion analysis for many reasons. 2D video analysis is simpler to set up and takes less time to perform. Most importantly, it is far less expensive to perform, requiring fewer cameras, hardware, and software in order to analyze sport movement. Another major advantage of 2D video is that it can be captured in a field setting and acceptable results are achieved for preselected planar movements. Conceptually, 2D video is easier for coaches and athletes to comprehend, making the findings more meaningful to the consumer.

Drawbacks of 2D video analysis include (1) the relative subjectivity of kinematic measurements (e.g., angles, distances, etc.) which are calculated by the eye/hand rather than reflective markers attached to the athlete; (2) inferior image resolution and sampling rates of video cameras, further reducing the overall accuracy of kinematic measurements; and (3) most digital video cameras that cannot be "genlocked" to allow shutter openings to be synchronized across multiple cameras [30]. While action cameras (i.e., GoPro™) allow multiple cameras to be synchronized to a single remote control, the lack of genlock capability can lead to error of up to half of a field (0.01 seconds) apart. Genlocking is possible with action video cameras but requires purchasing third-party hardware (e.g., MewPro™) to synchronize multiple cameras.

3D motion analysis has the advantage of capturing the body's true 3D movements with minimal distortion due to high sampling rates and superior image resolution. Angles between body segments can be calculated with a high degree of accuracy due to multiple camera views. Limitations of 3D motion analysis include cost, time, and the resource-intensive nature, including the need for a laboratory setting and an onsite biomechanist to assist with analysis performance and interpretation. Statistical reports generated from the analysis are often complex and difficult for the layperson to understand, thus making it difficult to translate the information into practical, actionable information that coaches can use.

Wearable Technology: Motus

More recently, the emergence of *inertial measurement units* (IMUs) have allowed for new means of throwing analysis. These IMUs, commonly referred to as *wearables*, are small sensors that typically contain a triaxial accelerometer and a triaxial gyroscope and are capable of recording data at up to 1000 Hz.

The most widely used and widely studied wearable in the sport of baseball is the motusBASEBALL™ by Motus Global. The motusBASEBALL™ is a small sensor measuring 38 mm × 25 mm × 10 mm with a mass of only 6.8 g. The sensor is placed inside a neoprene sleeve and worn on the throwing arm, resting approximately 1.5 inches distal to the medial epicondyle on the muscle belly of the flexor carpi ulnaris. Adjustments in the application's biomechanical algorithms allow for a 2-inch radius of IMU movement without the accuracy of the data being compromised. This technology has been recently used to evaluate arm stress in pitchers [32] and is gaining popularity within all levels of baseball.

The sensor's firmware contains 16Mbit of memory that automatically captures and stores data on arm slot (angle of forearm in relation to the ground at ball release), arm speed (peak rotational velocity of forearm in rotations per minute), arm rotation (maximal angle of the forearm during late cocking; in degrees), and elbow varus torque (Newton-meters) for each throw. This data is relayed to the mThrow™ mobile application via Bluetooth LE in real time, allowing for instant feedback.

The mThrow™ has been validated against the gold standard of 3D motion capture and was shown to have good to excellent correlations for arm slot ($r = 0.95$), arm speed ($r = 0.85$), arm rotation ($r = 0.94$), and elbow varus torque ($r = 0.93$) [33]. It has also shown high precision (>98% precision) across all pitch parameters for fastballs, breaking balls, and change-ups [34]. The use of the mThrow™ as a coaching tool should be considered given its high degree of precision, user-friendly interface, low cost, and ability to provide instant and meaningful feedback on kinematic and kinetic parameters.

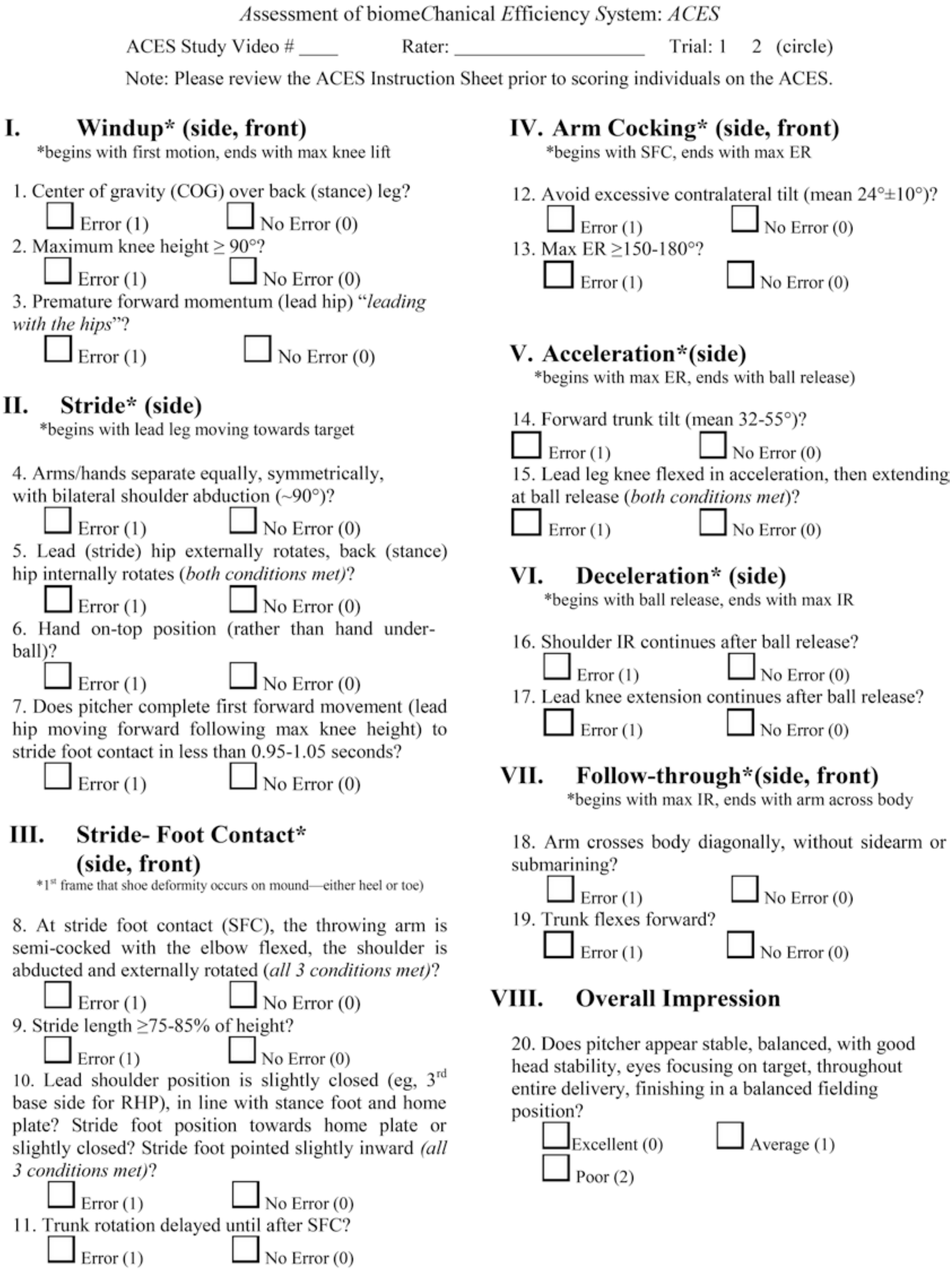
Clinical Correlates of Throwing Mechanics

The purpose of this chapter is to equip the clinician with a basic understanding of throwing mechanics analysis and certain critical key points that can contribute to increased injury risk or reduced longevity. The identification of a given mechanical flaw should alert the clinician to look for relevant impairments and address so that the coaching staff can then address the mechanical flaw.

A large proportion of mechanical errors are observed in the lower half, especially in youth throwers. Observation of a hip drop or trunk lean during the windup should cue the clinician to assess core strength (i.e., standard plank test), functional hip abduction strength (i.e., side-plank test; anterior step-down test; hip adduction excursion test), and stride leg ankle stability (i.e., single-leg stance on foam, eyes closed; modified BESS test). Early pelvic rotation should lead the clinician to ROM testing of the of stance leg internal rotation, which should be performed either passively in the prone position or actively in a modified weight-bearing position (on stool) as these are more specific to requisite stance leg motion demands. Flexibility and extensibility of the stride leg hamstrings and the stance leg hip flexors and rotators should be examined when a shortened stride length is noted. Landing on a stiff or too closed stride leg should lead the clinician to the evaluation of stride leg hip external rotation ROM, ankle dorsiflexion ROM, and quadriceps strength and extensibility.

Thoracic extension and rotation ROM as well as anterior core control should both be examined in the presence of early trunk rotation (i.e., failure to "stay closed") or excessive lumbar hyperextension during the cocking phase. Thoracic extension can be measured simply by taking standing AROM, while thoracic rotation can be measured most specifically by having the player seated on a stool with the drive hip rotated forward and then rotating the trunk toward the arm side.

Upper-half mechanical errors are commonly the result of lower-half errors earlier in the delivery, but local deficits can also contribute. Failure to achieve maximal ER during late cocking or consistently dropping the elbow below ~90° during acceleration should lead the clinician to assess total arc ROM as well as soft tissue restrictions in the pectorals, subscapularis, latissimus dorsi, and teres major. If capable, the clinician should also examine humeral torsion using diagnostic ultrasound, as this measure should be considered when evaluating total arc. Any upper quarter errors noted during the deceleration or follow-through phases indicate assessment for posterior capsular restrictions and eccentric weakness of the posterior rotator cuff.



*A*ssessment of biome*C*hanical *E*fficiency *S*ystem: *ACES*

ACES Study Video # ____ Rater: ____________________ Trial: 1 2 (circle)

Note: Please review the ACES Instruction Sheet prior to scoring individuals on the ACES.

I. Windup* (side, front)

*begins with first motion, ends with max knee lift

1. Center of gravity (COG) over back (stance) leg?
☐ Error (1) ☐ No Error (0)
2. Maximum knee height ≥ 90°?
☐ Error (1) ☐ No Error (0)
3. Premature forward momentum (lead hip) "*leading with the hips*"?
☐ Error (1) ☐ No Error (0)

II. Stride* (side)

*begins with lead leg moving towards target

4. Arms/hands separate equally, symmetrically, with bilateral shoulder abduction (~90°)?
☐ Error (1) ☐ No Error (0)
5. Lead (stride) hip externally rotates, back (stance) hip internally rotates (*both conditions met)*?
☐ Error (1) ☐ No Error (0)
6. Hand on-top position (rather than hand under-ball)?
☐ Error (1) ☐ No Error (0)
7. Does pitcher complete first forward movement (lead hip moving forward following max knee height) to stride foot contact in less than 0.95-1.05 seconds?
☐ Error (1) ☐ No Error (0)

III. Stride- Foot Contact* (side, front)

*1st frame that shoe deformity occurs on mound—either heel or toe)

8. At stride foot contact (SFC), the throwing arm is semi-cocked with the elbow flexed, the shoulder is abducted and externally rotated (*all 3 conditions met)*?
☐ Error (1) ☐ No Error (0)
9. Stride length ≥75-85% of height?
☐ Error (1) ☐ No Error (0)
10. Lead shoulder position is slightly closed (eg, 3rd base side for RHP), in line with stance foot and home plate? Stride foot position towards home plate or slightly closed? Stride foot pointed slightly inward *(all 3 conditions met)*?
☐ Error (1) ☐ No Error (0)
11. Trunk rotation delayed until after SFC?
☐ Error (1) ☐ No Error (0)

IV. Arm Cocking* (side, front)

*begins with SFC, ends with max ER

12. Avoid excessive contralateral tilt (mean 24°±10°)?
☐ Error (1) ☐ No Error (0)
13. Max ER ≥150-180°?
☐ Error (1) ☐ No Error (0)

V. Acceleration*(side)

*begins with max ER, ends with ball release)

14. Forward trunk tilt (mean 32-55°)?
☐ Error (1) ☐ No Error (0)
15. Lead leg knee flexed in acceleration, then extending at ball release (*both conditions met*)?
☐ Error (1) ☐ No Error (0)

VI. Deceleration* (side)

*begins with ball release, ends with max IR

16. Shoulder IR continues after ball release?
☐ Error (1) ☐ No Error (0)
17. Lead knee extension continues after ball release?
☐ Error (1) ☐ No Error (0)

VII. Follow-through*(side, front)

*begins with max IR, ends with arm across body

18. Arm crosses body diagonally, without sidearm or submarining?
☐ Error (1) ☐ No Error (0)
19. Trunk flexes forward?
☐ Error (1) ☐ No Error (0)

VIII. Overall Impression

20. Does pitcher appear stable, balanced, with good head stability, eyes focusing on target, throughout entire delivery, finishing in a balanced fielding position?
☐ Excellent (0) ☐ Average (1)
☐ Poor (2)

ACES score sheet

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3

Understanding Load in Baseball and Tennis

Ellen Shanley and Natalie L. Myers

Learning Objectives

Upon completion of this chapter, you will be able to:

- Describe the differences and importance of measurements of internal and external workload in baseball and tennis.
- Apply pitch count guidelines as found on the MLB Pitch Smart web page to a youth/adolescent pitcher to make recommendations to an athlete for safe participation.
- Design an appropriate seasonal competition and recovery schedule for an 8–12-year-old baseball team with four available pitchers.
- Identify workload factors that contribute to injury in tennis players.
- Recognize the technology available for workload monitoring in baseball and tennis athletes.

Introduction

Manipulation of workload in sport is critical to the development of physiologic capacity and enhancement of performance. In order to progress an athlete's physical capabilities, tissues must experience overload (external load) and appropriate recovery. Careful guidance of specific movement patterns and the dose-response of activities will cause a predictable and targeted physiologic response (internal stress) [1]. Improper management of training parameters has been thought to lead to tissue damage and injury [1–3]. The manipulation of volume, intensity, and frequency of loads through progressive resistance, periodization, specific adaptation of imposed demands (SAID), and other training principles has been documented since prior to the 1950s [4]. The continued advancement of player fitness, performance, and injury prevention has caused scientists to examine the management of training in athletes as a balance between player readiness and sport demand [3, 5].

The science of workload management continues to develop based on the many possible metrics used to quantify load and ways to study its impact on athletes. Training load has been described as a combination of external (quantity of training demand applied to the athlete) and internal load (personal response related to the sport-imposed demands) [6]. There are many ways to quantify both external and internal load

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without definitive evidence as to the metrics that most specifically influence performance and injury risk. Questions exist as to the best methods to analyze the impact of loading. Traditional study described the summary of total work (absolute workload) as critical in understanding the impact of training on an athlete's performance and health [6]. Bannister described the ratio of an athlete's fitness level compared to the applied acute workload as critical to understanding the impact of training on an athlete's performance and health [7]. Therefore, the purpose of this chapter is to understand current workload management in baseball and tennis. The secondary purpose of this chapter is to suggest the future needs and possible strategies to monitor training and competition workload and its relationship to performance enhancement and injury prevention in baseball and tennis.

Baseball has a history of tradition. The game continues to adapt with the addition of the designated hitter in the American League, instant replay, and the number and timing of coaching visits to the mound. The length of the major league season remains 162 games played over 6 months with few rest days. Athletes playing the game have also evolved becoming taller, faster, and more powerful. This increase in player fitness and performance combined with smaller ballparks and shrinking strike zones has influenced the strategy of baseball. Hitters try to force starting pitchers to throw more pitches early in the game and force the opposing team to utilize the more relief pitchers in each game [8]. These factors and several others seem to play a role in the current performance standards and the increased number of injuries at all levels of baseball [9, 10]. In baseball, upper extremity injuries happen more frequently than lower extremity injuries in all players but especially pitchers based on the stress of repetitive throwing [9, 11, 12]. These patterns continue even with the proliferation of studies focusing on physical risk factor identification and treatment [13–21].

Much like baseball, tennis has evolved since its inception in the 1870s [22]. Wooden-framed rackets were utilized until the 1970s, but as the speed of the game evolved so did the equipment. Modern racket frames are often made from graphite or fiberglass resulting in a light weight feel. Fitting racket frames with the correct string type and tension has become a science over the last several decades. The material of the strings along with the tension of the strings can be critical to performance as high-tension strings lend well to increased control and low-tension strings equal more power. As the equipment has evolved so have the physical demands of the sport. Elite level tennis players compete year-round [23], and as a result, the time for recovery during the competitive season is minimal. Year-round training that is not managed appropriately may be one reason for injury risk in tennis players. Dissimilar to baseball, in tennis the lower extremity is most frequently injured followed by the upper extremity and trunk [24]. However, upper extremity injuries may affect the tennis population with a greater time loss due to the frequency of overuse and chronic injuries [25].

Emerging evidence in other sports has identified that rapid increases in load rather than absolute load is a major risk factor for musculoskeletal injuries [26–30]. The impact of not only absolute but also spikes in workload may play a key role in understanding the impact of the individual outing and cumulative load on performance and injuries. The evidence also suggests that preparation of athletes in the preseason and after injury be carefully monitored to ensure the current workload does not exceed the athlete's fitness level [30].

Measurement of Workload in Baseball

Scientific measuring and understanding of workloads in baseball has been limited to the position of pitcher due to frequent and costly injuries. In 1999, Major League Baseball (MLB) began collecting pitch count data as a measure of a pitcher's workload. The use of pitch counts has been controversial for the management of the workload of professional pitchers. Supporters point to emerging evidence in the youth and adolescent literature that have associated pitching load with arm pain [31–35]. Critics point to the history of baseball and feats of players like Nolan Ryan, a legendary player seemingly immune to injury no matter how often he played or how much load he endured. Additionally, they argue that cumulative pitching load has not been associated with disabled list (DL) time in MLB pitchers and controlling game pitch counts has not been demonstrated to reduce injuries in professional pitchers [34, 36]. Checking pitch volume has led to a reduction in complete games by starting pitchers [34]. Prospective evidence has not linked volume and type of load to injury in professional pitchers, yet retrospective data has been published associating game pitching load to the need for revision surgery in professional pitchers recovering from ulnar collateral ligament (UCL) surgeries [37, 38].

Pitch count recommendations (available at: http://m.mlb.com/pitchsmart/pitching-guidelines) were originally set forth for youth athletes in 1996 [39]. The recommendations have been modified and expanded over time based on additional research [31, 32, 40]. More than 25 regional and national youth and adolescent organizations are considered fully compliant with current Pitch Smart pitch count guidelines [41]. Additional organizations support the guidelines both nationally and internationally. These organizations and the specific Pitch Smart guidelines including pitch count recommendations by age group for individual game pitch counts and rest days between pitch outings can be found on the MLB website [41]. In 2016, the National Federation of State High School Associations (NFHS) modified its pitching policies to require each state to adopt a pitching restriction and rest day rule based on actual game pitch counts rather than on innings pitched [42]. The NCAA does not currently have pitch count or rest guidelines for pitchers participating in collegiate baseball games. Pitch Smart (available at http://m.mlb.com/pitchsmart/pitching-guidelines) does have recommendations for college-aged pitchers (19–22 y.o.) for both game volume and rest days [41]. There is limited availability to game and seasonal pitch count data for youth, high school, collegiate [43], and minor league levels. MLB does not have mandated pitch count or rest guidelines for their organizations, yet the data is available both online and live during major league games. The lack of publicly available data for amateur pitchers, the documented lack of knowledge of game pitch count and rest recommendations by coaches, and multiple teams of pitcher participation further complicate quantifying the demands on young pitchers [33, 43, 44].

Current metrics [31–34, 40] used in baseball to understand an individual pitcher's workload have included absolute measures of external load. These external load metrics include game appearances, seasonal and average innings pitched, and total and average pitches per game and per season. Other metrics to quantify amateur player workload include months of the year pitched, number of back-to-back days pitched or played, games pitched or played on the same day, pitch types, total teams of participation, total showcase, and camp participation. These metrics have been helpful to understand the pitchers game involvement and stress.

Measuring Workload: Additional Measures

Game volume has limitations when used as a representation of workload in a baseball pitcher. The metric in isolation fails to account for the frequency of pitching, velocity (effort level), the pace of play (time between pitches), and the intensity of effort. For many relief pitchers, the variables of frequency (back-to-back games) and intensity (high-leverage situations) are concerns for performance and injury risk. A recent study of the pace of play rule changes has documented increased fatigue in the forearm musculature of pitchers operating under the considered recommendations [45]. The pace of play rule will need to be monitored to determine the impact on the individual and team workload.

Game volume cannot account for practice and pre-competition workload. Currently, recommendations for practice workload monitoring or restrictions have not been available. Recent studies have estimated the bullpen workload in high school pitchers exceeds overall pitching volume by an extra 30% [46]. The distance of the warm-up and workload during practice is variable for each individual player, but many pitchers regularly include long toss in their workout increasing arm stress during the season [47]. Closer monitoring of bullpen and practice throwing volume to understand the summative risk of the load endured throughout the season has been recommended [46].

Monitoring of internal load or the player's response to the stress of pitching has not been routinely implemented. The measurement of internal load in sport can take many forms including physiological (range of motion, strength imbalance), cardiac, biochemical, hormonal, psychosocial, or immunological measures [48–51]. Shoulder range of motion and eccentric strength have been shown to be altered after pitching performance [52, 53], and both metrics have been associated with increased injury risk [54]. However, the exact magnitude of change, the dynamic curve of the changes over time, and the degree of recovery between pitching performances all affect the magnitude of the internal load response and make it difficult to completely quantify the effect on injury. Recent reviews have recommended the use of heart rate, heart rate variability (HRV), or rate of perceived exertion (RPE) as noninvasive, useful, and feasible measures for monitoring individual athletes involved in team sports [6, 55]. Cornell et al. [56, 57] have examined the relationship between the stress of professional pitching to HRV response. The authors noted that a single simulated game of pitching caused a negative response from the pitcher's autonomic nervous system (lower resting HRV) 1 day after pitching with subsequent recovery prior to their next start [56]. An abnormal recovery of HRV between starts was theorized as a potential warning of overtraining and potential increased risk for musculoskeletal injury [56]. No studies were available that monitored workload using RPE in baseball [6]. Workload was studied examining balls bowled per week and RPE in cricket. The results of this study indicate that RPE multiplied by training time was helpful in documenting the increased risk of musculoskeletal injury. Further study of measures of internal load in baseball will be necessary prior to determining the benefits of routine monitoring of these metrics.

Measurement of Workload in Tennis

External workload measurement in tennis have lagged behind baseball despite the competition schedules. Youth pitch count recommendations have been refined over the past two decades as absolute pitching load is correlated to arm pain in baseball [31, 32]. Practice and match stroke volume recommendations for individual tennis players have yet to be presented. Optimal stroke volume per match and per season to balance performance and injury risk is not yet fully understood by competitors, coaches, or medical professionals. The main challenge to the management of a tennis player's workload remains the structure of tennis competition. Players are not removed from a match based on stroke volume, and the more successful the athlete is during a tournament, the greater the number of matches played. While removal from a tennis match is unrealistic due to the nature of the sport, stroke counts be used to more accurately monitor workload and progress of a tennis player through a training regime.

A few studies have successfully reported on typical match hitting volume during elite level tournaments in both professional and junior tennis players [58, 59]. These descriptive studies can be used to help determine the ceiling workload an elite level tennis player may encounter during competition enabling the player to progressively train for tournament play. Many tennis professionals and researchers quantify workload using metrics such as weekly minutes played and number of matches played [23, 60].

Measuring Workload: Additional Measures in Tennis

A recent systematic review suggested that monitoring internal workload during training should be considered as a capacity measure in sport [61].

Commonly used noninvasive internal workload metrics consist of heart rate and session rate of perceived exertion (sRPE). To our knowledge there are no studies correlating heart rate with injury likelihood in tennis players. However, heart rate has been examined during 85 minutes of match play in college tennis players and was found to be 145 ± 13 beats/min [62]. Additionally, tennis drills have elicited heart rates ranging between 178 and 182 beats/min [63]. Subjective internal workload monitoring has been documented in the literature on a small sample of elite players resulting in RPE ranging between 6 and 8. Using a variation of RPE, sRPE (session duration × RPE) has been shown to have a strong relationship to injury in team sports such as rugby, cricket, and Australian football [29, 64, 65].

The Future of Workload Monitoring in Baseball and Tennis

The advancement of equipment in sport science has led to the development of wearable technologies that include global positioning sensors (GPS), accelerometers, and often inertial movement units (IMUs) to quantify workload. These technologies have been used to track the activity, movement patterns, and demands for individual athletes. Early studies in baseball and tennis examined technologies to monitor swing, throwing motion, and movement distances [66].

Lately, a commercially available IMU with triplanar accelerometers and gyroscope technology has been studied to determine the precision and reproducibility of physical and performance measures, such as the amount, speed, and position of the arm during throwing [67]. The device was also able to indirectly quantify elbow varus torque during the throwing motion [67, 68]. The authors were able to discriminate between pitch types (fastball, curveball, and changeup) for each athlete. Anthropometric variances between pitchers such as height, weight, and elbow circumference were correlated with the amount of elbow torque and shoulder motion in individual athletes [67].

The device has been shown to be of value to monitor changes in mechanics and load within and individual athlete over time. While the technology has been correlated for the estimation of elbow varus torque in pitching to the gold standard laboratory-based motion capture, the comparison of other specific metrics between athletes has not been completely understood [68]. Several other opportunities exist to promote full-scale adoption of these technologies: application and maintenance of sensor placement, athlete willingness to wear the technology in training and competition [67], and effectiveness of feedback for athlete training.

IMU technology has also been used in tennis successfully classifying forehands, backhands, and overheads with 97% accuracy [69]. Racquet-mounted sensors such as the Sony Smart Tennis Sensor (SSTS) provide an alternative to IMU technology and can display stroke and count data in real time along with variables such as speed and impact location. Triaxial accelerometry and gyroscopes have also been used to process ball speed. Keaney et al. [70] did report good correlations between criterion measures of ball speed and racquet-mounted sensor speed scores. GPS technology has been used on court to determine total movement. Total distance covered during tennis training was found to be similar between clay and hard courts [71]. While total distance was used as a measure of external workload in a small sample of junior male players, no injury or performance data were correlated with movement distance on court.

Overload in Baseball and Tennis

Overload in sports has been related to errors in the prescription, monitoring, and execution of practice and competition loads [30, 72, 73]. The volume and intensity of preparation must exceed previous loads in order to stimulate improvement in performance [1]. An imbalance between fatigue and current fitness level can either maximize performance (low fatigue/high fitness) or increase injury risk (high fatigue/low fitness). The application of high current workloads to an athlete that is underprepared or that hasn't adequately recovered often leads to an overloaded state [49–51].

In baseball, the rate of pitchers experiencing time-loss injuries in the first months of the season suggests that these athletes are underprepared for the increased practice and competition workload at the beginning of the season [9, 11, 74]. Chambliss et al. documented that among minor league players, those at the rookie level spent approximately 7 times more days recovering from injuries than those at higher levels [75]. They hypothesized that the difference was related to the stress of higher competition levels and the player's lack of readiness for this load [75]. Previously injured youth and adolescent baseball players who advanced in level of play were 1.6 times as likely to develop an additional overuse injury in their upper extremity than athletes that did not advance in competition level [76]. The overload situations that occur early in the season or to players quickly advancing in level of play seem related to a mismatch of preparation to sport demands [76].

Cumulative pitching volume has been demonstrated in youth and adolescent players as a risk factor for the development of shoulder and elbow pain [31, 32]. Pitching on multiple teams during the same season and pitching in multiple games on the same or back-to-back days were also related to the development of arm pain in youth and adolescent pitchers [33]. Injuries seemingly related to increased volume and frequency of workload may be related to either readiness or lack of recovery creating an overload situation.

In tennis, epidemiologic studies consistently have one finding in common, that upper extremity and trunk injuries are more chronic in nature compared to the lower extremity in which acute injury occur more frequently [24]. The chronic onset of upper quarter injuries suggests that investigating factors that contribute to overload at these joints may lead clinicians and researchers to potential effective prevention strategies.

From a biomechanical perspective, the tennis serve is often studied due to its complex movement patterns. The serve places high demands on the player's musculoskeletal system. Improper kinetic chain loading and lower and upper extremity range of motion can lead to increased torque resulting in overload and future injury [77–80]. More recently, investigators have begun to explore the possibility of varying volume factors that could potentially lead to overload and injury risk.

The combination of rigorous practice schedules and numerus tournaments per year often result in a demanding schedule with little time for rest and recovery. In fact, junior players are three times more likely to medically withdraw when participating in greater than five matches during a tournament [23]. Additionally, playing more than 6 hours/week has been found to be a risk factor for back pain [60]. When tournament matches and weekly playing hours begin to reach threshold values, clinicians and tennis professionals should exercise caution and incorporate additional recovery sessions to counteract a potential overloaded situation.

Specific Athletes at Risk for Overload

Overload injuries present as overuse injuries with a gradual not distinct injury date. Certain baseball and tennis players are predisposed to develop an overload problem. These athletes have inherent factors such as a history of injury [60, 81, 82], history of high loads without proper recovery [23, 31, 32, 40, 77], or impairments in range of motion (ROM) [13, 60], or strength may increase their risk of developing a musculoskeletal injury [83]. These athletes should be closely monitored for signs or symptoms of overload. Some athletes are more susceptible to injury because of factors external to them [83]. For instance, an athlete that has had limited preseason participation because of regular and postseason participation in another sport, recovery from injury, or other reasons may be less tolerant of sport-specific loads [83]. These athletes will require a slower assumption of standard seasonal workloads and require continued monitoring of common physical impairments and performance characteristics provide early clues to potential overload.

Warning Signs of Overload

Overload issues should be suspected when athletes demonstrate declines in performance that have persisted over a significant amount of time. Pitchers often complain of loss of control and fatigue or a "dead arm" when they have experienced increased load without adequate recovery [84]. Other symptoms of overload include the development of pain, prolonged soreness, interrupted sleep patterns, changes in resting heart rate, and complaints of burnout.

Longitudinal monitoring of workload and both systemic and musculoskeletal recovery including restoration of range of motion (ROM), strength, and endurance are important to identify athletes at risk for decreased tolerance to sport-specific loads [85]. Based on an athlete's specific impairment, appropriate recovery activities should be implemented to support the pitcher's musculoskeletal health. Understanding an individual's tolerance to sport-specific stressors will help design a schedule that balances the load necessary to maximize performance and recovery. Continued monitoring of load and impairments can assist support staff in maintaining the season-long health of both pitchers and tennis players.

Conclusion

Additional research is needed to assess the effectiveness of current safety guidelines for youth and adolescent pitchers. Future tennis research should incorporate both external and internal workload monitoring in relation to injury and performance. Current research is underway to investigate workload measures, injury risk, and performance over an 8-month period in elite junior players. Adherence to the guidelines, establishing a communication plan that emphasizes reporting of signs and symptoms of potential overload, and monitoring individual athlete's response to cumulative workload and recovery are critical steps to maintain the health of individual pitchers.

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4

Why Is the Athlete in Your Office? Making the Right Diagnosis in the Disabled Throwing Shoulder

John M. Tokish and W. Ben Kibler

Introduction

The disabled overhead athlete remains one of the most challenging patient populations for the clinician surgeon to treat. There are many reasons for this. To begin with, presenting symptoms are often varied and may include shoulder pain, mechanical symptoms, a sense of looseness, or loss of speed or control. The patient's history is often one of insidious onset, with complaints that are only reproduced while in the act of throwing, and, as such, very difficult to reproduce in an orthopedist's office setting. In addition, the physical examination can be confusing and challenging. Contributing factors to the clinical presentation are not localized to the shoulder but may be identified in many areas of the kinetic chain. In addition, very few shoulder examination tests are sensitive and specific enough to result in high levels of diagnostic accuracy. While in many patients the clinician can compare the injured to the normal side, the throwing athlete has a number of normal variable adaptations that include increased external rotation, decreased internal rotation, altered scapular position, adaptive laxity, and periscapular muscle atrophy. Unfortunately, imaging is often misleading as well. "Pathologic" findings such as superior labral abnormalities and rotator cuff tendinosis or partial tears are often present in the normal thrower, making it challenging to differentiate between normal adaptation and abnormal pathologic changes. Finally operative decision making remains more art than science. Overtreatment may address the pathology but leave an athlete unable to throw. Any surgical intervention with subsequent rehabilitation will take a toll on the kinetic chain, and significant periods away from training the kinetic chain can, in itself, endanger the thrower. Thus, the clinician must be prepared to invest the time and comprehensive team approach to accurately diagnose these athletes and to understand the individual delicate nature that results in returning them to throw. Once an accurate diagnosis is obtained, it must be applied to the individual athlete to achieve an optimal result.

Value on the Front End

Much effort is currently being made to identify, quantitate, and improve the value associated with the outcomes of treatment of medical conditions. Outcomes are typically defined as how the patient did after an intervention and may be termed "value on the back end" of the treatment process.

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There has not been the same amount of effort related to improving the process for making the diagnosis, the "value on the front end" on which the treatment is based.

Most physicians treating symptomatic throwing athletes feel that patients come to their office to get treated for a specific anatomic injury such as a rotator cuff tear, a labral injury, or instability that can be described with an ICD-10 code. The traditional diagnostic process is designed to discover the anatomic injury. When the anatomic diagnosis is established, the content and timing of the treatment can be formulated. This relatively straightforward approach has not been shown to consistently result in comprehensive and accurate diagnoses and effective treatment. Examples can be given for labral injury [1, 2], impingement [3, 4], rotator cuff disease [5, 6], acromioclavicular joint injury [7], clavicle fractures [8], and instability [9]. This has led to efforts to develop a more effective diagnostic process.

The Institute of Medicine (IOM) has recognized the central importance of the diagnosis in health care. In September 2015, the IOM produced the latest report in its highly regarded Quality Chasm Series, titled *Improving Diagnosis in Health Care* [10]. The report documented troubling deficiencies in the effectiveness of developing the diagnosis in all health-care disciplines. Some of the summary findings included the following:

- "Delivery of health care has proceeded for decades with a blind spot – the failure to effectively determine the diagnosis."
- The diagnostic process can be improved, but it will require a re-envisioning of the entire process.

Central to this re-envisioning is a broader definition of the diagnosis and an understanding of the multiple patient factors that may be included in the diagnosis. A more comprehensive definition of diagnosis is "that body of information, collected through the process of evaluating the patient's health problem, that determines the content and timing of the treatment of the health problem" [10]. The patient's health problem frequently consists of more than a discrete anatomic injury. Many clinical problems in overhead athletes result from a process of injury and may involve multiple local and distant deficits. The diagnosis also encompasses the patient's experience with the problem, his or her limitations with the problem, and the expectations of recovery from the problem.

A survey of patients presenting with shoulder pain revealed that 83% related their concern to a problem of lack of function, not a specific injury [11]. Their expectations were that they wished to have this dysfunction returned to function. Function is the outcome that is assessed by most outcome measures. Therefore, function and dysfunction should be the predominant factors in the diagnosis.

Physical function is the ability to complete a specific task. For most overhead athletes, function involves accurately, forcefully, and repetitively placing the arm and hand (and frequently an object in the hand) in a position to optimally throw, hit, support, push, or pull. Physical function has been characterized as anatomy, acted upon by physiology, to produce mechanics. Dysfunction, or the alteration of function, involves pathoanatomy but also frequently involves pathophysiology and pathomechanics. These deficits must be evaluated in the diagnostic process.

It has also been demonstrated that patient-specific factors may play a substantial role in the success of treatment and determination of outcomes. They are individualized, are "brought" to the injury by the patient, and should be included in the evaluation. Multiple factors including depression, catastrophization, and job status/satisfaction have been shown to affect treatment and outcomes [6, 12–18]. Questionnaires have been developed to assess these factors [19–22].

Based on these current thoughts, a model can be developed that guides the diagnostic process and subsequent treatment (Fig. 4.1). The patient's presenting problem consists of clinical symptoms (pain, instability, click/pop, trouble sleeping, decreased motion) and patient dysfunction (inability to throw/serve, inability to push/pull,

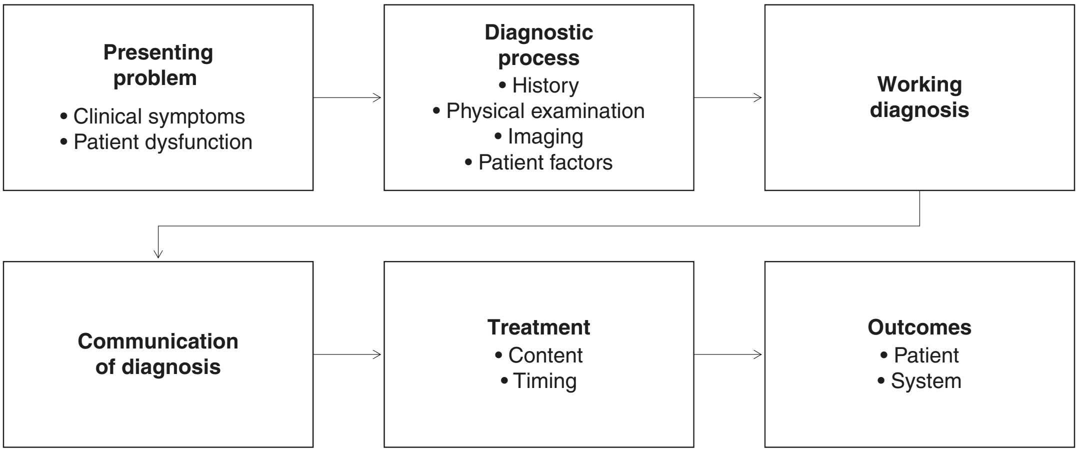

Fig. 4.1 Diagnostic process model

decreased ball velocity/location). The diagnostic process should include the history and the local and distant clinical exam to include anatomical injury (rotator cuff, labral, ligamentous), physiological deficits (muscle flexibility, strength, balance), and biomechanical alterations (joint range of motion, changes in throwing/serving motion). Imaging should be used when indicated and is designed to be confirmative, only infrequently totally diagnostic. Patient-specific factors can be assessed at initial evaluation and help to highlight these issues which may need to be developed.

Several points can be made regarding the applicability of the model to orthopedics and shoulder surgery. First, it is sequential, starting with the patient experiencing some type of alteration of his or her normal functional status. Second, it emphasizes the key role for comprehensive information gathering from multiple sources to develop the diagnosis to be more than an International Classification of Diseases, Tenth Revision code. Third, it emphasizes the involvement of the patient in determining treatment after the diagnosis is made. Fourth, the treatment includes content and timing of the interventions. Finally, the treatment results in outcomes, which the IOM report describes as patient outcomes (observed or measured by clinicians, reported by patients) and system outcomes (quality, cost, safety, efficiency, public confidence in the system). In this model, there is a linear, almost cause-and-effect relation between the diagnosis and the outcome. The implications from this model are, even though much effort and many resources are being expended to determine the outcomes of treatment, the "value on the back end," as much effort should be placed into improving the diagnostic process, to develop the "value on the front end" that can guide more effective treatments.

This model can also demonstrate how diagnostic errors can occur. Diagnostic errors may be defined as "the failure to develop the information required to establish an accurate and timely explanation of the patient's health problem, and failure to meaningfully communicate the information to the patient" [10]. The information must be accurate (not differing from the actual patient problem, imprecise, or incomplete) and timely (not delaying the correct treatment). It also must be communicated to the patient in understandable terms so that the patient can participate in the determination of the treatment plan.

There are demonstrated deficiencies in the diagnostic process and the resulting diagnoses in shoulder surgery. In general, they often result in imprecise and incomplete information. They often fail to identify the actual anatomic lesion and the associated physiological and biomechanical alterations, fail to include patient-reported factors and expectations, do not adequately define what functional loss exists, and are inconsistent

Table 4.1 Information that is important but often not included in diagnoses related to overhead athletes

Diagnosis	Omitted information
Labral injury	Glenohumeral internal rotation deficit (GIRD) Scapular dyskinesis Kinetic chain deficits
Impingement	Rotator cuff disease Labral injury Instability Biceps tendonitis Adhesive capsulitis Patient-specific factors
Rotator cuff injury	Labral injury Altered shoulder rotation Scapular dyskinesis Postural deficits Patient-specific factors
Acromioclavicular (AC) joint injury	Anterior/posterior AC joint laxity Rotary AC joint laxity Scapular dyskinesis
Clavicle fracture	Distal fragment anterior rotation Scapular dyskinesis
Scapular dysfunction	Weakness: Lower trapezius/serratus anterior Tightness: Pectoralis minor/upper trapezius/latissimus dorsi Core weakness and/or instability Patient-specific factors
Medial elbow injury	GIRD Scapular dyskinesis Kinetic chain deficits
Lateral elbow injury	Posterior shoulder weakness

in guiding treatment, and they only infrequently are associated with predictability of outcomes. There is also anecdotal but widely believed evidence of overuse of imaging in the diagnostic process and overdiagnosis of many shoulder problems [23]. Most frequently for overhead athletes, the error will result in an imprecise or incomplete diagnosis (Table 4.1). This can alter or delay the treatment.

In summary, the overhead athlete is in your office because he or she is concerned about an alteration of function, a dysfunction, and they wish to have the function restored. The dysfunction has components of pathoanatomy, pathophysiology, and pathomechanics and can be affected by individualized patient-specific factors. The complete and accurate diagnosis includes pertinent information from all of these areas and will be communicated to the athlete to create a treatment protocol.

Information can be organized as the 5 As [24]:

- Accuracy: All anatomic, physiological, and biomechanical alterations that accompany the health problem should be evaluated and categorized.
- Assessment: The process should include patient-specific factors and expectations and meaningful communication to ascertain patient acceptance and involvement.
- Agreement: The process should result in high interrater reliability for the process and the content of the evaluation.
- Applicability: The process should result in reliable guidance for the content and timing of all the aspects of the comprehensive treatment plan.
- Accountability: The information should be able to reasonably relate to predictions of outcome.

As doctors and clinicians continue to search for methods to improve the quality, safety, efficacy, and value of treatment, devising better surgical techniques or more precise measurements of outcomes will not necessarily be of maximal benefit unless equal attention is placed on improving the diagnosis on which the techniques and subsequent measurements depend.

Understanding the Context of the Disabled Throwing Shoulder

One of the most challenging aspects to treating the disabled throwing shoulder (DTS) is that it is, in many respects, the final common pathway of an intricate series of events beginning in the core, moving through the kinetic chain, and resulting in the release of a ball moving at a tremendous speed. Dysfunction in any one of these events will affect all downstream chain events. If one is to understand the DTS, one must also understand each step that transfers input energy to the shoulder during throwing and the shoulder's role in transferring output energy to the final parts of the chain. Further, the clinician must understand whether the dysfunctional event is anatomic, physiologic, or biomechanic. If there is anatomic structural damage, it is unlikely that rehabilitation will solve the issue, and if it is physiologic, rehabilitation may be the mainstay of treatment. Therapists, coaches, and surgeons have differing backgrounds and areas of expertise, and are not generally trained in the fine points of recognizing pathology across disciplines. Thus the clinician must learn to speak other disciplines' languages and employ a team of experts from across specialties to address the complexities of the DTS. A basic understanding of the framework of the kinetic chain is a good place to begin.

Role of the Kinetic Chain

The thrown ball is the result of a sequential and coordinated kinetic chain of force development requiring a specific set of body positions and motions [25, 26]. The kinetic chain has several functions [27]: (1) using integrated programs of muscle activation to temporarily link multiple body segments into one functional segment to decrease the degrees of freedom in the entire motion [28, 29]; (2) providing a stable proximal base for distal arm mobility; (3) maximizing force development in the large muscles of the core and transferring it to the hand [30, 31]; (4) producing interactive moments at distal joints that develop more force and energy than the joint itself could develop and decrease the magnitude of the applied loads at the distal joint [26, 32–35]; and (5) producing torques that decrease deceleration forces [26, 36, 37].

While biomechanically technical, these functions have real clinical implications. One mathematical model showed that a 20% reduction in trunk kinetic energy resulted in 70% more mass in the distal segments to maintain the same energy at ball impact [25]. An additional study in tennis players showed that failure to adequately flex the knees in the cocking phase of serving resulted in a 17% increase in shoulder load and a 23% increase in elbow valgus load when velocities were maintained [38]. Other examples correlate decreased hip range of motion associating with shoulder injury and poor throwing mechanics [39].

Thus if one is to understand the disabled throwing shoulder, one must understand the "abled" throwing shoulder, which in turn requires a thorough understanding of the shoulder's proper place within the kinetic chain. While no comprehensive "ideal" evaluation system has been established, advances have been made in this area. Recently, Myers et al. [40] reported a validated method of observational analysis in tennis players. Players with improved flexibility and power demonstrated superior mechanics during the tennis serve, and there was good consistency among raters in their objective evaluation of the serve.

History Considerations in the Disabled Throwing Shoulder

Ultimately, the answer to the question, "why is this athlete in your office," is a simple one: he or she can't throw. A proper understanding of why this is the case is the cornerstone of all treatment and begins with a thorough and individualized history. There is a communication gap that exists between patient and clinician and even between clinicians of different specialties. A patient may seek an understanding of why "it hurts when I throw." The surgeon may speak of a partial thickness tear of the supraspinatus, the therapist may diagnose tightness of the posterior capsule, and the pitching coach may address this as failure to correctly get to the top of the slot. All may have a portion of the truth, but the effective clinician must be able to understand all of these perspectives and their languages and ultimately communicate back to the patient the answer of why they are in your office.

The Chief Complaint

The patient with a chief complaint of "I can't throw" should first be asked, "why not?" The answer to this question is the first critical step in

Table 4.2 Pain-related DTS: questions and considerations

History question	Clinician consideration
Did the pain start with one single event or insidious?	Single: suggests anatomic structural damage Insidious: suggests overuse
Where exactly is the pain when you get it?	Top of shoulder: acromioclavicular joint Greater tuberosity: rotator cuff In the back: internal impingement, labral pathology, posterior shoulder tightness In the front: biceps pathology, scapular dyskinesis
When do you get it?	Acceleration: internal impingement, cuff Follow-through: biceps, posterior shoulder tightness
Onset: Is it immediate or only with prolonged use?	Immediate: structural abnormality Prolonged use: overuse, physiologic overload, chain issues
What helps it?	Stretching: posterior shoulder tightness Strengthening/thorough warmup: dyskinesis, muscle imbalance

formulating the ultimate diagnosis, as it can create an early differential diagnosis to guide the rest of the history and physical examination. It is patient centered, meaning that the answer to this first question individualizes the remainder of the clinical encounter, workup, and ultimate treatment plan. It is also efficient, as it focuses specifically on the patient's complaint, and avoids the pitfalls of a generalized "one size fits all" approach. It, however, can be quite varied and complex. Answers such as pain, clicking, a loss of velocity, a loss of ball control, a sense of fatigue, numbness or deadness, or even the sense that they can't "get into the right slot" are all common patient perspectives to explain their inability to effectively throw. The history can then be guided to specifically address the original source, progression, and response to treatments of this complaint. If pain is the athlete's perception for why he or she can't throw, the history should focus on finding the source of this pain. Table 4.2 provides guidance on historical questions when an athlete's DTS is related to pain.

Clicking or popping is a common complaint by a disabled thrower. It is important to differentiate between clicking that is symptomatic and that which is just present, but not painful or mechanical. In the former, mechanical clicking generally represents a structural abnormality, and one's suspicion should gravitate toward labral pathology, loose bodies, or chondral defects. Painless and nonmechanical clicking is common and is often due to subacromial crepitance. This is often temporary and can be treated with rehabilitation and reassurance.

Numbness or deadness often leads the clinician to consider neurologic or vascular sources. This is an important part of the workup of these patients, as thoracic outlet syndrome is a well-recognized source of disability in throwers [41–43]. This suspicion may take a clinician down a different algorithm toward unique physical examination findings, imaging workup, and even specialist consultation and thus is an excellent example of why the original question of the patients' perspective on "why" they can't throw is so critical. It is important to note, however, that a chief complaint of numbness or loss of control can be due to abnormalities within the kinetic chain and shoulder. Shoulder instability, labral tears, and muscle weakness are also common sources of this complaint, and thus a complaint by the athlete of numbness or deadness is not an automatic referral to a thoracic outlet or spine specialist.

Finally, athletes who can't throw due to loss of velocity or control can be some of the most difficult to sort out. This sensation can be due to defects in the kinetic chain, structural abnormalities, or biomechanical alterations in form. This set of complaints often requires the sports medicine physician to rule out structural or anatomic abnormalities, a therapist to rule out kinetic chain weaknesses, and the pitching coach to rule out biomechanical maladaptations.

Clinical Course and Progression of Care

Once the chief complaint is understood, and the clinician has an initial differential in mind, the clinical course of the complaint from its inception to the present is obtained. Responses to treatment, such as periods of rest, anti-inflammatories, or steroid injections, even if temporary, are important for diagnostic as well as therapeutic considerations. Time courses are also critical. With the pressure to perform, even at the youth and high school levels, there is often an urgency to treat the disabled throwing shoulder. Thus patients and their parents often will present for a surgical evaluation after "failing physical therapy" over the course of a few weeks. It is incumbent upon the clinician to trace the history of present illness thoroughly to ensure that conservative treatments that have been prescribed have been appropriately applied.

Current Status and "Degree of Disability"

It is important to understand the current status of the patient. An in-season condition that is being played through will likely be managed differently than an off-season injury that results in complete disability. This requires an understanding of the patient's competitive goals and where they are in their season or career. It is also important to understand their access to resources, such as physical therapy, coaching, and medical care.

The final aspect to the current status of the problem is the *degree of disability* incurred by the athlete from their condition. This can vary from minimal annoyance with high-level sports to complete disability with activities of daily living. Understanding where the patient is on this spectrum greatly aids in guiding how aggressive the diagnostic workup is and how invasive the treatment plan should be. It is important to note that an accurate assessment of the degree of disability may require communication with the athletic trainer or physical therapist, because some athletes may attempt to "play through" injuries that render them ineffective and put themselves in danger of further injury. These are sometimes difficult decisions for an athlete to make, and often a trainer's input is valuable in defining the degree of disability.

Past Medical History and Review of Systems

Although athletes are among the healthiest patients in our population, questions about past medical history should not be neglected. These include questions about medications, allergies, and congenital or other medical problems. Finding out that a swimmer with shoulder pain has Ehlers-Danlos syndrome might not only point to multidirectional instability (MDI) as a diagnosis but will undoubtedly influence the treatment of such a shoulder. Although often negative, a review of systems and queries regarding past medical history can avoid missing key aspects affecting the diagnosis and eventual treatment of the overhead athlete.

At the completion of a well-structured history, the clinician should have a fairly strong initial clinical suspicion of "why the patient is in your office." With this in mind, the physical examination can be guided to strengthen or refute these suspicions on the way to an accurate clinical diagnosis.

Physical Examination Considerations in the Disabled Throwing Shoulder

A comprehensive evaluation program is necessary to evaluate the thrower, both in terms of injury potential and understanding the patterns of alteration in injury. Just as the throw itself begins with the lower extremities and the core, so too should the examination of the disabled throwing shoulder. This will be covered in more depth in Chap. 5, but a brief discussion can illustrate some common and key principles in the evaluation.

A proper functioning core is critical to successful throwing. Deficiencies in the core often result in overloading of the shoulder and can lead to injury. This is especially true in adolescent and preadolescent athletes who often have underdeveloped posterior chain musculature (gluteals, hamstrings, erector spinae). This aspect of the core can be evaluated with a single leg squat (Fig. 4.2) and has been shown to be deficient in a

Fig. 4.2 Single leg squat. This image shows the importance of a stable squat, with no collapse or lean. (**a**) Performance in front of a mirror can provide biofeedback to the patient to improve performance. (**b**) As the athlete progresses, perturbations can be added to add an additional challenge to core stability during the maneuver

high percentage of adolescent athletes [44]. Other defects of the proximal kinetic chain can have detrimental effects on the shoulder [45]. One study of NCAA athletes has demonstrated that poor performance on functional movement screening and Y-balance tests (assessments of core stability) correlated with shoulder injury and shoulder surgery [46]. Thus an evaluation of core strength and functional stability should be a part of the evaluation of every patient with a disabled throwing shoulder.

Scapular Considerations

The upper extremity evaluation of the disabled throwing shoulder must begin with the scapula. The scapula forms the stable fulcrum from which the arm can achieve the key positions necessary to successfully throw a ball with velocity and control, and deficits or dyskinesis of the scapula may result in altered performance and increased injury risk. The normal mechanics of scapular motion in the throwing shoulder are scapular retraction, upward rotation, posterior tilt, and balanced rotation [27]. The dysfunctional scapula often demonstrates deviations from this even in the resting position, but the changes can be subtle. In an effort to aid the clinician in an accurate and comprehensive evaluation for scapular dyskinesis, a consensus meeting was established [47], and a standardized approach to clinical observation was developed [48, 49]. The testing protocol begins with an evaluation of inflexibilities (pectoralis minor and humeral rotation deficits), and the resting position of the scapula is noted [50, 51]. Tightness of the pectoralis minor can be estimated by asking the patient to stand with their back against the wall and measuring the distance from the wall to the coracoid on each side. A difference greater than 3 cm is considered positive for pec minor tightness [27]. The dynamic motion of the scapula is evaluated with the arms moved into forward flexion and descent. Medial scapular prominence is noted as dyskinesis. If positive and provocative, the examiner performs corrective maneuvers to determine if these maneuvers alter the symptoms. One test is the scapular assistance test**.** This test is performed while the patient attempts to raise their arm overhead. The examiner depresses the upper medial border of the scapula while he or she pushes the inferior border laterally to assist in upward rotation and posterior tilt. This test can decrease external impingement symptoms [52]. The scapular retraction test depresses the medial border of the scapula along its course and can increase rotator cuff strength and decrease internal impingement symptoms in the setting of labral injury [53, 54].

The role of the scapula in the disabled throwing shoulder was originally defined by Burkhart et al. [55] and refined by Kibler [27], 10 years later. Originally referred to as a SICK (*S*capular malposition, *I*nferior medial border prominence, *C*oracoid pain and malposition, and dys*K*inesis of scapular movement) scapula, much has been learned about adaptation and pathologic changes of scapular mechanics. The principles of tightness of the pectoralis minor and weakness of the lower trapezius and serratus anterior have stood the test of time and remain cornerstones in the treatment of the scapular component of the disabled throwing shoulder. Adaptations do exist, however, and scapular dyskinesis can be found in normal asymptomatic athletes [56, 57]. Thus the scapular examination must be taken in context of the total picture. Correction of symptoms with assistive maneuvers is suggestive of the clinical relevance of the dyskinesis to the clinical symptoms.

GH Rotation Deficits

In 2003, Burkhart et al. introduced the concept of GIRD (glenohumeral internal rotation deficits) as a key component of the disabled throwing shoulder [58]. In that paper, the authors described "symptomatic GIRD" as a side-to-side difference >25° and proposed that the underlying posterior capsular tightness that caused it was the source of the disabled throwing shoulder. This work did call attention to the alterations, both adaptive and pathologic, that are seen in the disabled throwing shoulder, and much work has been done to refine these initial observations. Tokish et al. reported that up to 40% of asymptomatic professional pitchers displayed GIRD by any of the common definitions and cautioned against using GIRD in a vacuum to diagnose pathology [59]. Several authors have shown that GIRD is, in part, due to adaptive humeral bony retroversion [60, 61], and Kibler has shown that GIRD increases both acutely and over several days after a throwing workout [62]. This "thixotropy" is postulated to result from acute or chronic sarcomere strain leading to stiffness, which can be addressed with stretching. Thus, GIRD should be approached with caution as it can be a normal adaptation but should also be understood as a potential source of disability in the throwing shoulder. A more recent description of pertinent motions in the throwing shoulder includes total rotational range of motion (TROM). This measurement takes into account adaptations in both external and internal rotation and may give early evidence of potentially deleterious alterations in rotation. Most studies show that TROM is symmetric in throwers and servers but should not exceed 186° as an absolute number. A 5° asymmetry in TROM has been shown to be predictive of increased injury risk [63]. In order to consistently measure these motions, a disciplined approach should be employed. The patient should be laid supine with the scapula supported. A goniometer should be used, and the arm should be rotated only until the scapula demonstrates initial movement. Players demonstrate changes in their measured motions over the course of a game and season [64, 65], and the "curve of change" or the ability to return to baseline may be the most important measurement. Changes that do not resolve with posterior capsule and horizontal adduction stretching and are associated with pain should be carefully watched and treated.

Shoulder-Specific Examination

Once the kinetic chain and appropriate ranges of motion have been considered, the shoulder itself should be examined. Particular attention should be placed on an attempt to reproduce the patient's actual symptoms. As noted, at this point in the workup, the clinician should have a strong suspicion of the differential diagnosis, and we use the physical examination to confirm or refute these suspicions. Thus we employ the physical examination of the disabled throwing shoulder by beginning with a suspected diagnosis first and then perform the associated provocative tests associated with this pathology, which is the opposite of the method commonly taught in medical school and residency. In our experience, this approach is more efficient and more accurate.

Table 4.3 Provocative physical examination tests in the disabled throwing shoulder

Suspected diagnosis	Physical examination "musts"
Internal impingement	Apprehension test for pain, relocation test
Symptomatic posterior tightness	GIRD, cross body adduction deficit with pain
Cuff pathology	Impingement signs of Neer and Hawkins, Jobe's test, resisted external rotation
Superior labral pathology	Active compression test, modified dynamic labral shear test, internal rotation resisted strength test
Instability	Apprehension for reproduction of symptoms, posterior push-pull test for symptomatic posterior instability, symptomatic sulcus sign for multidirectional instability
Biceps tendonitis/ partial tearing	Active compression test, biceps groove tenderness, speed's test

A list of these diagnoses and their recommended confirmatory tests are included in Table 4.3, which begins with a potential diagnosis and then tests it with physical examination findings.

It should be noted that the purpose of these provocative maneuvers is to reproduce the patient's symptoms as exactly as possible. When tests of a particular differential are positive and the others are negative, this is strong evidence that the diagnosis is correct. Unfortunately, this is often not the case, as there is commonly overlap and coexistent pathologies present in the shoulder. In addition, some throwers only display symptoms during throwing. In such cases, observing the athlete throwing or communication with the athlete's coach or trainer may shed clarity on the exact positions of provocation.

Imaging

While a detailed description of the specific imaging findings in the throwing shoulder is beyond the scope of this chapter, there are a few important concepts that will help the physician to use imaging to enhance their ability to determine why the athlete is in their office.

X-ray evaluation and advanced imaging are critical components of the disabled throwing shoulder. As in most cases, standard radiographic imaging begins with a shoulder X-ray series and in many cases is all that is necessary. It is important to remember that more than 99% of competitive throwers do not get paid to throw and are often young and playing multiple sports. Standard X-ray evaluation may show the hallmarks of Little Leaguer's Shoulder which includes proximal humeral physeal widening or metaphyseal bony changes. This finding is often confirmatory in an adolescent or preadolescent, and no further study may be required. Even when the X-rays are negative, the clinical examination is often sufficient for treatment, and should not prompt an automatic MRI.

Nevertheless, the MRI has become the cornerstone in the evaluation of the throwing shoulder, and while it can be an incredibly helpful tool in confirming a diagnosis [66], there are some important points to discuss in this regard. The first is that the MRI should be used primarily as a confirmatory and supportive tool, not as the cornerstone of diagnosis. Miniaci et al. [67] demonstrated that 79% of asymptomatic professional baseball players demonstrate abnormal signal in their cuff and labrum. This has been confirmed in little league players as well, where over half of asymptomatic players demonstrate abnormalities on MRI [68]. Overreliance on an MRI can be detrimental to a correct diagnosis, resulting in the overtreatment of adaptive change interpreted to be pathologic. It is therefore critical that clinicians who care for the throwing athlete be proficient in reading the MRI themselves as it is best used in combination with knowledge obtained in the history and physical examination. Advanced imaging can be helpful in confirming the diagnosis and as a preoperative planning tool. The conventional axial view allows good tangential visualization of the posterior inferior labrum, while the oblique axial view allows better tangential visualization of the posterior labrum.

Providing Value on the Back End to the Disabled Throwing Shoulder

One area that has been deficient, especially in the treatment of the throwing shoulder, is measurement of specific and accurate outcomes after treatment. This may be described as a search for "value on the back end" or how well do the treatments return the athlete to their desired level of function? Tibone, for example, reported on the results of acromioplasty in an elite throwing population [69]. Despite excellent improvements in pain relief, only 4 of 18 pitchers returned to throw at their preinjury status. This early report called out the challenges of measuring outcomes in the throwing athlete. Traditional self-reported outcome tools have consistently demonstrated a "ceiling effect" in throwers, which limited the ability to document incremental improvements at the higher end of function [70]. In response, outcome scores specific to throwing populations have been developed. Alberta et al. debuted the Kerlan-Jobe Orthopaedic Clinic overhead athlete's score (KJOC) [71], in a population of throwing athletes. Domb et al. [72] applied it to throwers who underwent ulnar collateral ligament (UCL) reconstruction. In that paper they found that the KJOC score was the most sensitive score for detecting subtle changes in performance in the throwing athlete. Neuman et al. reported similar findings in a population of throwers who underwent shoulder surgery and concluded that the KJOC score provided a more stringent assessment of overhead athletes' function than the ASES score [73].

Sauers et al. have developed the "Functional Arm Scale for Throwers" (FAST). Their approach was to employ a disablement model to more fully evaluate the health-care quality of life of the thrower. The FAST score evaluates the "whole-person" health-care disablement model which takes into account emotional and social factors in addition to limitations in throwing [74]. A subsequent article by the same authors demonstrated that the FAST score is a reliable, valid, and responsive scale for measuring patient-reported health-care outcomes in throwing athletes with injury [75] and has been found to be an effective measure of disability in a population of female softball pitchers.

Thus, just as the throwing shoulder is unique from a diagnostic perspective, the evaluation of outcomes in these patients requires specialized attention to their individual requirements. We would recommend the KJOC and FAST scores as routine tools in the evaluation of outcomes in this specialized population.

Conclusions

The disabled throwing shoulder is a complex diagnostic dilemma. Keys to ultimate success include understanding the athlete's chief complaint, formulating an early differential diagnosis, and using the physical examination and imaging to confirm the correct source of the patient's disability. The evaluation of treatment outcomes requires special attention to the specific specialized activities and scores required of this population. Thus the disabled throwing shoulder requires meticulous attention from presentation, through diagnosis and treatment, with an in-depth evaluation of outcomes. The patient is in our office for a reason. It is incumbent upon the clinician to determine that reason and to assist in returning them to throw.

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Principles of Physical Examination

5

Aaron D. Sciascia and W. Ben Kibler

Introduction

Overhead athletes can perform their desired and specific tasks because of utilization of the kinetic chain. This coordinated, sequenced activation of body segments places the distal segment in the optimal position at the optimal velocity with the optimal timing to produce the desired task [1]. Alterations in the kinetic chain, either anatomical injuries and/or physical impairments, have been associated with shoulder injury [2–10]. This relationship between injury and kinetic chain dysfunction/deficiency suggests that an evaluation approach that goes beyond the assessment of the site of symptoms is necessary to correctly identify the root cause(s) that may be creating symptoms.

The "non-shoulder" shoulder examination, a screening examination of areas proximal to the shoulder that often are associated with shoulder injury, can assist clinicians to understand the entire spectrum of alterations in the kinetic chain that contribute to the diagnosis of shoulder injury in overhead athletes [11]. If alterations are found, a more specific and detailed orthopedic examination can be employed. Due to the complexity of the throwing motion and the reliance on the kinetic chain segments working optimally as a unit, a comprehensive evaluation program that assesses anatomical segments proximal and distal to the site of symptoms is necessary to evaluate the thrower. A comprehensive but efficient clinical examination should include elements from three anatomic areas: the core (legs, hips, and trunk), the scapula, and the shoulder/arm. The core and scapula examination represents the "non-shoulder" part of the shoulder examination.

Core Examination

The kinetic chain model suggests that improvement of common deficiencies within the core (immobility of the pelvis, hip, and/or trunk, muscular weakness of the same areas, and alterations in muscle recruitment and timing) would decrease the risk of injury to the upper extremity. There are biomechanical data and some anecdotal clinical findings that support the relationship between core strength and/or stability and upper extremity injury occurrence [8, 10, 12–14]. However, to date no comparative studies have been performed to determine if upper extremity performance improves following the application of core stability or strength interventions.

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Fig. 5.1 Trendelenburg stance to detect gluteus medius weakness

No standard way has been described to measure core strength [1]. Different investigators have used different techniques to try to gauge the relative strengths of specific core muscles via EMG data [15] and isometric dynamometer values [16–19]. This data can give some rough estimate of core strength. Firing of numerous muscles in task specific patterns to provide core strength makes evaluation of any specific single muscle as a reference point questionable. Any evaluation technique will need to take into consideration that the muscles to be tested should be tested in functional positions when possible.

One option to assess core strength that incorporates many of these variables is to look at one-leg standing balance ability via the Trendelenburg maneuver and a single leg squat [1]. In a standing balance test, the patient is asked to stand on one leg with no other verbal cue. Deviations such as a Trendelenburg posture or internally or externally rotating the weight-bearing limb indicate inability to control the posture and suggest proximal core weakness (Fig. 5.1a, b). The single leg squat would be the next progressive evaluation if the standing balance test is done well. Assuming the same starting point as the standing balance test, the patient is asked to do repetitive partial quarter to half squats with no other verbal cues. The patient may present with one or more of four possible deviations. First, the patient may only perform a 1/3 squat. This posture does not require high levels of abductor muscle activation. The 1/2 squat will more readily demonstrate any existing abductor muscle weakness. Second, the patient may use the arms for balance or may go into an exaggerated flexed trunk position (Fig. 5.2a). This excessive flexion forces the lower extremity into a false negative, optimally aligned position as the body attempts to balance on the decent phase of the squat. Third, the patient's knee may move into an exaggerated valgus position on decent (Fig. 5.2b). This would suggest that a proximal deficiency in strength and stability is present. Finally, the patient may dynamically rotate the leg as a unit on the decent phase of the squat. This has also been termed "corkscrewing" due to the rotary motion that occurs during this maneuver. Presence of any or all of these deviations is indicative of poor proximal control of the lower extremity.

Bilateral hip rotation range of motion (ROM) should be assessed as deficits in rotation have been associated with shoulder and elbow injury [7, 13, 20]. The athlete should be seated to stabilize the pelvis, and manual motion into internal and external rotation should be performed.

Scapular Examination

The goals of the physical exam of the scapula are to establish the presence or absence of scapular dyskinesis, to employ dynamic corrective maneu-

Fig. 5.2 Positive findings of leg/pelvis weakness as demonstrated by (**a**) excessive trunk flexion as a compensation to align the knee during squatting and (**b**) valgus knee on decent phase of squat

vers to assess the effect of correction of dyskinesis on symptoms, and to evaluate joint, muscle, and bone causative factors. An outline for a consistent scapular evaluation is presented in Fig. 5.3. The key elements are clinical observation of the presence or absence of dyskinesis and demonstration of the effects of the corrective maneuvers. If dyskinesis is determined to be an element of the clinical presentation, then the examination can focus on the causative factors. The results of the exam will determine the relation of the dyskinesis to the clinical presentation, will aid in establishing the complete diagnosis of all the elements of the dysfunction, and will help guide the content of treatment and rehabilitation. Scapular dyskinesis is an alteration of static position and dynamic motion that may be considered a possible impairment of scapular roles in shoulder function. It has multiple possible causative factors, which can be determined by the examination.

The scapular exam should largely be accomplished from the posterior aspect. The scapula should be exposed for complete visualization. The resting posture should be checked for side-to-side asymmetry but especially for evidence of a SICK (Scapular malposition, Inferior medial border prominence, Coracoid pain and malposition, and dysKinesis of scapular movement) scapula position [21] or inferior medial or medial border prominence. If there is difficulty with determining the bony landmarks of the inferior

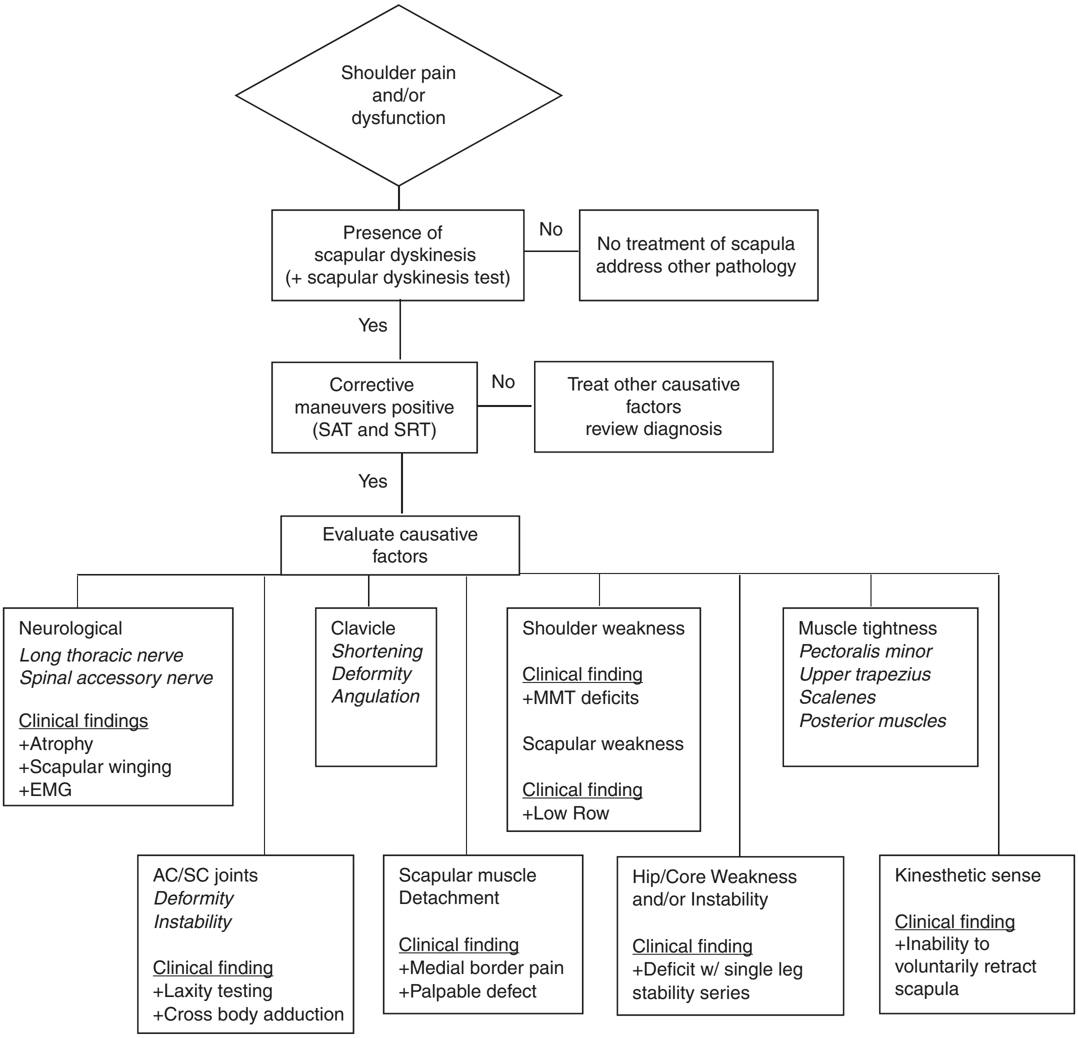

Fig. 5.3 Comprehensive shoulder assessment algorithm

medial or superior medial angles, marking the superior and inferior medial borders may help ascertain the position. Overhead athletes will have soft tissue adaptations that create a slightly lower resting position, but the inferior medial border should not be asymmetrically prominent or resting laterally on the thorax.

The sternoclavicular (SC) and the acromioclavicular (AC) joints should be evaluated for joint tenderness or instability, and the clavicle should be evaluated for angulation, shortening, or malrotation. This is a critical component of the scapular examination due to scapular function relying on optimal integrity of the clavicle and its articulation with both the acromion and sternum. The clavicle is the only bony attachment of the scapula and arm to the axial skeleton. The clavicle functions as a strut to maintain scapular position and to guide and constrain scapular motions during muscle activations and arm motions. The SC joint allows and constrains certain clavicle motions that then allow scapular motion, and the AC joint directly allows and constrains certain scapular motions [22]. The AC joint is a key component of normal scapulohumeral rhythm. It acts as a pivot around which the scapula can move in efficient motions. Intact clavicular rotations and intact AC ligaments create a reproducible screw

Fig. 5.4 Example of scapular dyskinesis showing medial border and inferior angle prominence

axis of motion between the two bones and allows three-dimensional motions [23]. Both the AC and SC joints and the clavicle require nearly normal anatomy to be able to allow normal scapular motions. Anterior/posterior AC joint laxity can be evaluated by stabilizing the clavicle with one hand and grasping and mobilizing the acromion in an anterior/posterior direction with the other hand.

Identifying the presence or absence of the physical impairment called scapular dyskinesis is best accomplished by observation of scapular motion using the scapular dyskinesis test [24–26]. This motion requires activation of the muscles to maintain the open chain mechanism of scapulohumeral rhythm. Failure to maintain this rhythm can result in increased scapular internal rotation, with consequent medial border prominence. The dyskinesis is more easily observed in the descent phase of arm motion. The exam is conducted by having the patients raise the arms in forward flexion to maximum elevation and then lower them 3–5 times, with a 3–5 pound weight in each hand [24, 25]. Prominence of any aspect of the medial scapular border on the symptomatic side is recorded as “yes” (prominence detected) or “no” (prominence not detected) [27] (Fig. 5.4).

Fig. 5.5 Scapular assistance test

The scapular assistance test (SAT) and scapular retraction test (SRT) are corrective maneuvers that can alter the injury symptoms and provide information about the role of scapular dyskinesis in the total picture of dysfunction that accompanies shoulder injury and needs to be restored [26, 28]. The SAT helps evaluate scapular contributions to impingement and rotator cuff strength, and the SRT evaluates contributions to rotator cuff strength and labral symptoms. In the SAT, the examiner applies gentle pressure to assist scapular upward rotation and posterior tilt as the patient elevates the arm (Fig. 5.5). This test has shown “acceptable” inter-rater reliability [29]. A positive result occurs when the painful arc of impingement symptoms is relieved and the arc of motion is increased. In the SRT, the examiner first grades the strength in forward flexion following standard manual muscle testing procedures (Fig. 5.6a) or evaluates the labrum by the modified dynamic labral shear

Fig. 5.6 Scapular retraction test. The examiner applies traditional muscle testing procedures (**a**) followed by repetition of the procedures with the scapula stabilized in retraction (**b**)

(M-DLS) test [30]. The examiner then places and manually stabilizes the scapula in a retracted position (Fig. 5.6b). A positive test occurs when the demonstrated strength is increased or the symptoms of internal impingement in the labral injury are relieved in the retracted position. Although these tests are not capable of diagnosing a specific form of shoulder pathology, a positive SAT or SRT demonstrates the role of the dyskinesis in producing the symptoms and indicates the need for inclusion of early scapular rehabilitation exercises to improve scapular control [26].

An assessment technique that may be used to assess for composite scapular retraction capability is the low row maneuver. While standing, the patient is asked to place his or her arm in slight humeral extension and then instructed to resist movement of the arm into forward flexion. Asymmetric weakness in retraction or lateral scapular tilt indicates reduced capability in the lower trapezius and rhomboids. The examiner (positioned posterior to the patient) then instructs the patient to contract the gluteal muscles while applying the same anterior force on the arm. If strength increases with the gluteal contraction, this is an indication that scapular muscle activation may be facilitated by involving hip and core strength.

Clinical experience has demonstrated that soft tissue weakness is often seen in combination with other impairments, especially tightness of the muscles attaching to the coracoid process. Coracoid-based inflexibility can be assessed by palpation of the pectoralis minor and the short head of the biceps brachii at their insertion on the coracoid tip. The muscles will usually be tender to palpation, even if they are not symptomatic in use, can be traced to their insertions on the ribs and arm as taut bands, and will create symptoms of soreness and stiffness when the scapulae are man-

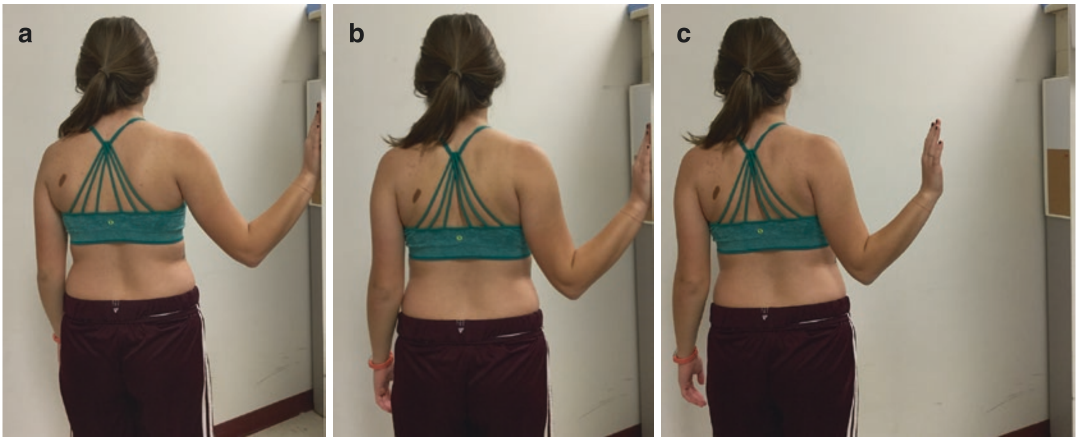

Fig. 5.7 Loss of kinesthetic sense assessment. The patient begins with the hand placed on a wall and the arm below 90° abduction (**a**). The patient is asked to actively place the scapula in a retracted position (**b**). The patient is then asked to step away from the wall while maintaining the retracted position (**c**)

ually maximally retracted and the arm is slightly abducted to approximately 40–50 degrees. Other muscles commonly found to be stiff and tight are the upper trapezius and latissimus dorsi. They will be painful to palpation in the middle of the muscle and will demonstrate increased tightness and pain upon stretch, by tilting the head laterally or raising the arm in maximum forward flexion.

It is possible for patients to present with an inability to actively perform or control scapular retraction, giving the scapula the appearance of "dancing" when active scapular retraction is attempted. This phenomenon is similar to demonstrated loss of kinesthetic sense in other anatomical regions of the body. To determine if this loss of retraction control exists, instruct the patient to place the hand of the involved arm on a wall with the elbow flexed to 45–60° (Fig. 5.7a–c). The patient should then attempt to retract the scapula. If retraction cannot be actively controlled or cannot be performed, then the test is positive for a loss of kinesthetic sense. This is a key finding and indicates that restoration of the sense of voluntary scapular placement must precede any scapular exercise that requires active muscle contractions to retract or move the scapula.

A common combination of soft tissue factors is weakness of lower trapezius and serratus anterior demonstrated strength and pain and reactive tightness of the pectoralis minor, upper trapezius, and latissimus dorsi. This pattern of associated alterations is called lower trapezius insufficiency (LTI). It has been demonstrated in 68% of patients with soft tissue-related, nonsurgical scapular dyskinesis. It is thought that failure of activation of the lower trapezius from inhibition, fatigue, or direct blow trauma leads to serratus anterior weakness and reactive stiffness/tightness in the pectoralis minor, upper trapezius, and latissimus dorsi.

Shoulder Examination

Standard glenohumeral exam techniques should be employed to evaluate for internal derangement. Special attention should be paid to the examination for altered rotation including internal, external, and total range of motion and the evaluation of labral injuries, both of which are associated with dyskinesis. The methods of assessing shoulder rotation and motion include (1) internal and external rotation at 90° abduction [31] and (2) horizontal adduction with the arm at 90° flexion and the scapula restricted from moving into abduction [32]. These methods have demonstrated acceptable levels of reliability for clinical use and provide clinicians with multiple assessment methods for assessing shoulder rotation and motion [33].

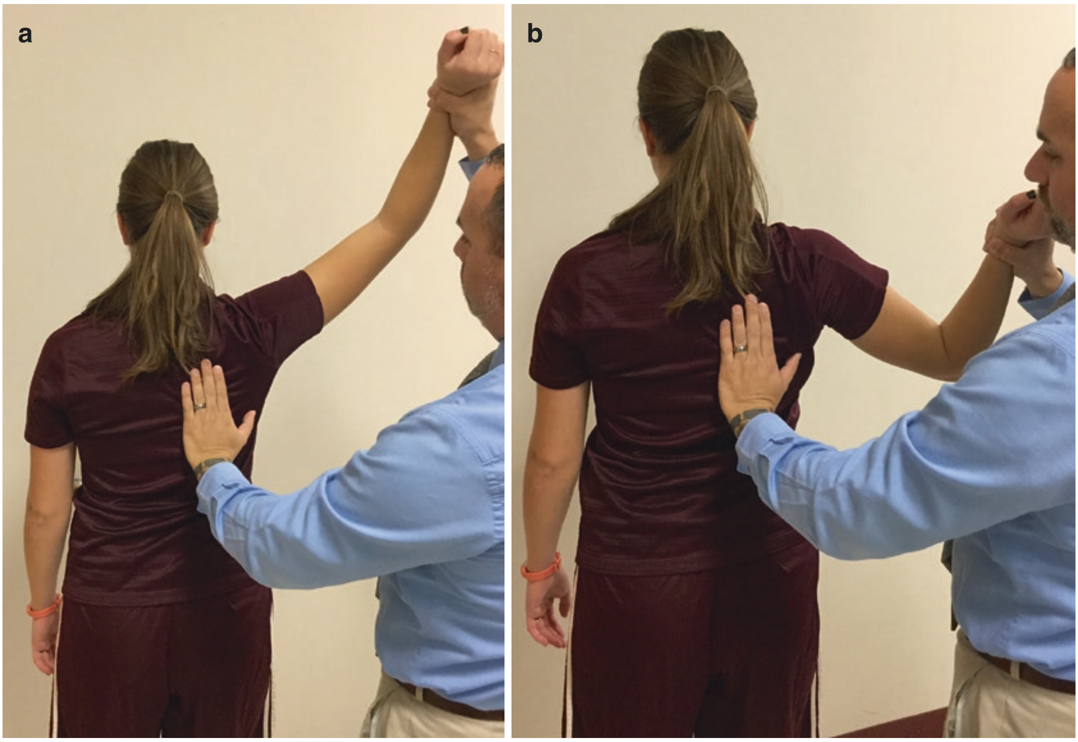

Fig. 5.8 The modified dynamic labral shear (M-DLS) test is performed by passively externally rotating the arm in 120° of abduction (**a**) and then shearing the humeral head against the labrum and glenoid (**b**)

The clinical tests suggested to evaluate rotator cuff strength actually measure a composite of local and distant muscle activations and joint stabilizations to produce torque at the shoulder to move or stabilize the arm [34]. The most consistent method to measure muscle power for glenohumeral external rotation, forward flexion, or abduction is to stabilize the scapula in neutral retraction [35–38]. This minimizes the proximal contributions, maximizes the scapular-based muscles' ability to contract, and, by eliminating the other variables, produces the best test/retest values, so that longitudinal change in strength over time can be most accurate.

Assessment for labral injury can be challenging, considering that little to no consensus exists in the literature regarding which examination components are important for identifying a clinically significant labral injury [39]. Various special tests designed to clinically identify superior labral injury have been developed with only a few having adequate clinical utility [40, 41]. One such test is the M-DLS test which has strong clinical utility to detect labral injuries [30]. To evaluate labral injuries using the M-DLS test (Fig. 5.8a, b), position the patient standing with non-corrected shoulder posture. Flex the elbow of the involved arm to 90°, abduct the humerus in the scapular plane to above 120°, and externally rotate to tightness. Gently guide the arm to maximal horizontal abduction. Apply a shear load to the joint by maintaining external rotation and horizontal abduction and lowering the arm from 120° to 60° abduction. A positive test is indicated by reproduction of the pain and/or a painful click or catch in the joint line along the posterior or superior joint line between 120° and 90° abduction. Be cautious when placing the arm into maximal horizontal abduction as excessive overpressure and positioning can result in a false positive test and/or create pain throughout the entire motion. This test has been shown to

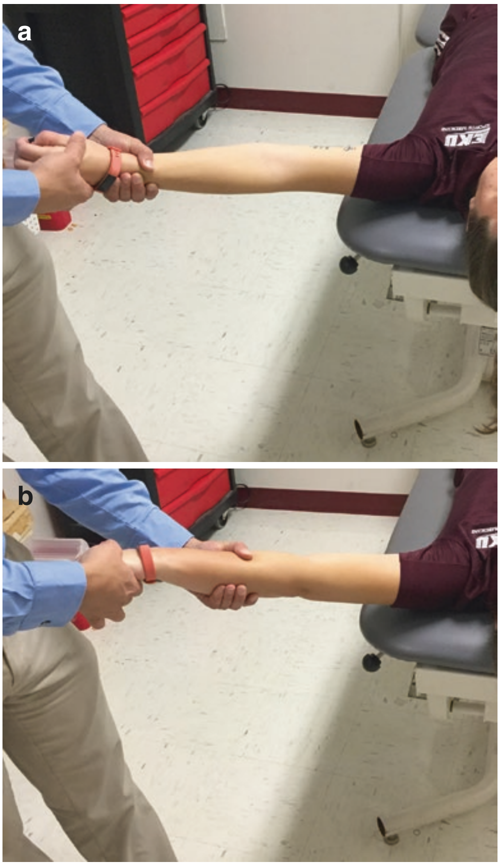

Fig. 5.9 The passive distraction test requires passive distraction (**a**) followed by the application of passive internal rotation (**b**) to stress the superior labrum

have strong clinical utility and has been recommended as a maneuver to be utilized clinically [30, 41].

Other maneuvers include the passive distraction and passive compression tests [41]. The passive distraction test is performed with the patient in a supine position and the arm positioned in 150° of elevation with the elbow extended and forearm supinated (Fig. 5.9a) [42]. The examiner passively pronates the forearm while maintaining the humerus in the 150° elevated position (Fig. 5.9b). A positive finding would be complaints of pain internally either anteriorly or posteriorly. Conversely, the passive compression test is performed with the patient side-lying and the arm in 30° of abduction (Fig. 5.10a) [43]. The examiner stands posterior to the patient, stabilizing the affected shoulder by holding the AC joint with one hand and the elbow with the other. The examiner passively externally rotates the shoulder and then pushes the arm superiorly while simultaneously extending the shoulder (Fig. 5.10b). A positive finding results in either pain or a click in the GH joint. It is believed that the M-DLS, passive distraction, and passive compression tests have strong clinical value due to their ability to replicate the peel-back phenomenon of labral pathology [44].

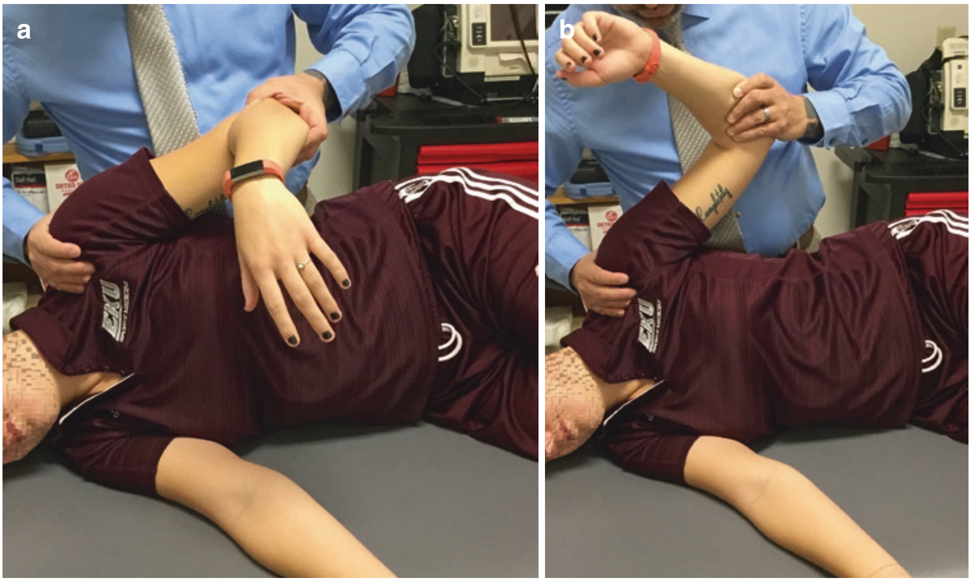

Fig. 5.10 The passive compression test is performed by compressing the humerus (**a**) followed by passive external rotation (**b**)

Summary

Assessment of all joints involved in the kinetic chain including those distal to the site of symptoms is important for making an accurate and complete diagnosis. The "non-shoulder" shoulder examination should not be overlooked and can be helpful in determining if key segments within the kinetic chain (scapula, trunk, and/or legs) could be contributing to the pain and/or injury. Traditional shoulder examination components that have strong clinical utility may help clinicians make more accurate diagnoses. The examiner must understand that the body both succeeds and fails as a unit; therefore performing a comprehensive examination can help distinguish between the victim (the site of the painful symptoms) and the culprit(s) (the local and distant musculoskeletal alterations that are associated with the injury). It also identifies all of the elements that need to be addressed in the rehabilitation process, which in many cases can reduce the need for surgery.

It may appear that this type of in-depth evaluation may be too time consuming to be effective. However, performing the evaluation in a stepwise screening manner will ensure a comprehensive overview of all of the possible factors contributing to the clinical presentation and will highlight the areas that need more detailed evaluation.

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6

Principles of Surgical Evaluation and Techniques for the Shoulder in the Overhead Athlete

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Introduction

The process of internal impingement and associated changes in total arc of motion, including glenohumeral internal rotation deficit (GIRD) and their relationship to superior labrum anterior-posterior (SLAP) tears and rotator cuff injuries, have been well studied [1–5]. Internal impingement of the shoulder is a condition characterized by excessive repetitive contact of the infraspinatus tendon with the posterior-superior aspect of the glenoid when the arm is in the abducted and externally rotated position. This contact leads to tearing of the rotator cuff and peel-back-type tearing of the posterior-superior labrum [6]. There has been some controversy on whether internal impingement is a pathologic condition or a normal adaptation to the activity the shoulder is performing as it has been described in asymptomatic shoulders without evidence of pathologic change [7, 8]. However, an overhead athlete's shoulder typically performs repetitive activities at the limit of the functional arc of motion, utilizing significant force. Such conditions have been shown to result in soft tissue and osseous adaptations [4, 6, 9–11]. In elite level throwers, for example, these adaptations allow the shoulder to be mobile enough to reach extreme positions of rotation to result in significant velocity. However, at the same time, the shoulder needs to remain stable with the humeral head centered within the glenoid, thereby creating a stable fulcrum for rotation; this has been described as throwers' paradox [9]. It is when the balance between extreme motion and stability becomes pathologic that we reference the condition known as a "disabled throwing shoulder" [3, 5, 12, 13].

In 1985, Andrews et al. [2] first observed SLAP tears in throwing athletes, which he treated with arthroscopic debridement. Andrews et al. [14] then described the association of the SLAP tear with partial thickness rotator cuff tears in the throwing shoulder. Snyder subsequently described SLAP lesions in the general population and established a grading system but did not specifically relate them to overhead athletes [15]. Walch et al. [8] described impingement on the undersurface of the posterior supraspinatus tendon and/or anterior infraspinatus tendon by the posterior-superior glenoid that occurs in the abducted and externally rotated position. Jobe [7] later described this as posterior-superior glenoid impingement or internal impingement based on observations in overhead athletes. He hypothesized that internal impingement in throwers would worsen due to gradual repetitive stretching leading to anterior microinstability. Because of this, Jobe et al. [16] performed an open anterior capsulolabral reconstruction, reporting mild suc-

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cess with 68% overhead athletes returning to play at their prior level of competition [16]. In 2001, Burkhart and Morgan first reported on 53 baseball players, 44 of whom were pitchers who had type II SLAP lesions that were surgically repaired after failure of nonoperative treatment. All of the type II SLAP lesions were located over the posterior-superior quadrant of the glenoid (posterior SLAP) or over the posterior and anterior quadrants (combined anterior-posterior SLAP) [17]. Arthroscopic repair of these type II SLAP lesions returned 87% of these athletes to sport, but the level of return was not really quantified [3]. These improved successes over open anterior capsulolabral repairs led the investigators to postulate that at least some of the anterior microinstability treated in the past may actually be more of a pseudolaxity associated with SLAP lesions [3].

Pathoanatomy

In order to be successful, an overhead athlete must be able to achieve significant velocity, which is most directly related to the amount of external rotation that the shoulder achieves [18]. To achieve this hyper-external rotation, bony and soft tissue adaptive changes occur within the glenohumeral joint, which include increased humeral retroversion and anterior capsular laxity. These anatomical adaptations and associated pathologic conditions are in part related to adaptive changes that result in response to the repetitive overhead activities. In addition, the range of motion in the throwing arm changes over time. The total arc of motion, including maximum internal and maximum external rotation in the abducted arm, is typically around 180 degrees in developing individuals. In elite overhead athletes, the arc of motion is shifted posteriorly with increased external rotation and decreased internal rotation [19, 20]. Some authors argue that the increase in external rotation is caused by an adaptive increase in humeral retroversion, and any internal rotation deficit of greater than 20 degrees is related to soft tissue adaptations [9].

There are a number of soft tissue adaptations that contribute to joint mobility. Overhead athletes often present with an increased sulcus sign on physical examination, which may be caused by laxity of the rotator interval structures due to repetitive microtrauma in the throwing position. Patients also present with hyper-external rotation, which is likely related to repetitive micro tears due to the cam effect in the abduction/external rotation position and possibly unrelated to increased humeral head and glenoid retroversion [21–23]. Due to the combined increased humeral head/glenoid retroversion and anterior capsular laxity, these potentially pathologic anatomic changes can occur with anterior instability and posterior capsular contracture, which subsequently produces glenohumeral internal rotation deficit [5, 18, 24, 25].

In order to obtain supra-physiologic range of motion, overhead athletes have undergone the aforementioned adaptations at the glenohumeral joint. These adaptations are accommodated by stretching the capsular structures and remodeling the osseous architecture. Additionally, forces of up to 750 newtons have been shown to be absorbed by the posterior-inferior aspect of the capsule on the follow-through phase of throwing [26, 27]. The resultant repetitive distraction forces cause posterior capsular remodeling leading to a posterior capsular contracture and subsequent glenohumeral internal rotation deficit. Burkhart et al. [5] felt that the most important pathologic process in overhead athletes is a loss of internal rotation in the abduction/external rotation position. This GIRD potentially results in rotator cuff tears and labral lesions if posterior capsular stretching is not instituted. As the posterior-inferior capsule becomes contracted, this shifts the glenohumeral contact point posterior and superior during overhead activities. The overhead athlete compensates for this tightness by externally rotating excessively around this new contact point, which shifts the vector of the biceps tendon to a posterior position and increases torsion on the posterior-superior labrum (i.e., peel-back position). This also causes abnormal laxity in anterior capsule ligamentous structures and increases torsional stress upon the posterior-superior rotator cuff [4, 5, 7, 17]. This can result in a SLAP tear and posterior-superior rotator cuff tear.

Additionally, Kibler has noted the significance of the position of the scapula in all of the aforementioned findings. Scapular protraction or dyskinesia in the throwing athlete allows earlier internal impingement, creating more irritation and peel-back-type tearing of the posterior-superior labrum. This dyskinesia limits the ability of the rotator cuff to keep the humeral head centered, resulting in decrease in velocity and increased risk of injury [11].

Surgical Management

Introduction

The majority of overhead athletes with internal impingement and associated conditions will respond to nonoperative management. It is critically important that scapular dyskinesia be addressed during rehabilitation to increase chances of nonoperative management working. However, those that do not respond and have continued pain and mechanical symptoms during throwing as well as positive MRI arthrography findings are often indicated for arthroscopic surgical treatment. Burkhart et al. [5] reported that 90% of all throwers with symptomatic GIRD (greater than 25 degrees) responded positively to a compliant posterior-inferior capsular stretching program to reduce the condition to an acceptable level, which was defined as (1) less than 20 degrees or (2) less than 10 degrees of the total rotation seen in the nonthrowing shoulder. This was accomplished over a 2-week time period with what he described as “sleeper stretches” [5]. The 10% non-responders tended to be older elite pitchers who have been throwing for years. The arthroscopic findings in these patients included a severely contracted and thickened posterior-inferior capsular recess (up to 6 mm) in the area of the posterior band of the inferior glenohumeral ligament (PIGHL) for which they performed a selective posterior-inferior capsulotomy in addition to a SLAP repair. The authors reported an immediate 65-degree increase in glenohumeral internal rotation following the capsulotomy. They also emphasized the importance of an immediate postoperative internal rotation stretching program to prevent the capsulotomy gap from closing during the healing phase.

Partial thickness articular-sided rotator cuff tears in association with internal impingement in overhead athletes have been well described in the literature [1, 8, 11, 28–31]. The result of excessive external rotation caused by GIRD has been shown to increase the shear and torsional stresses in the posterior-superior rotator cuff [7, 17]. Only a few studies have examined the recovery from the injury. Samani et al. [32] noted an 83% rate of return to play in a series of 25 overhead-throwing athletes, 52% of whom had concomitant rotator cuff tears that were debrided. However, the majority of patients in this series were recreational athletes. Pagnani et al. [33] suggested that the presence of a rotator cuff injury negatively predicted return to play in patients undergoing surgical repair of a SLAP tear.

In professional baseball players, surgical treatment of full thickness rotator cuff tears often results in few athletes returning to the same level of play. Mazoue and Andrews [34] reported on professional baseball players with full thickness cuff tears, and only 8% were able to return to the same level of play postoperatively. In 2012, Van Kleunen et al. [1] reported on return to high level of throwing after a combination of infraspinatus repair, SLAP repair, and capsular release for the glenohumeral rotation deficit. The infraspinatus was repaired only if the tear was >50% of the tendon thickness. Seventeen high-level baseball players younger than 25 years old underwent simultaneous arthroscopic SLAP repair and infraspinatus rotator cuff repair with either a free polydioxanone (PDS) suture or suture anchor. Only 35% were able to return to the same preinjury level. The Kerlan-Jobe Orthopaedic Clinic (KJOC) overhead athlete shoulder and elbow score was found to be significantly worse in patients undergoing repair of the infraspinatus with a suture anchor compared with those in whom a PDS suture was utilized. There were only three patients in the study who were treated with suture anchors for partial thickness infraspinatus tears. Thus, the free PDS suture repair technique was utilized in most patients to minimize the amount of iatrogenic trauma to the tendon repair. The authors mentioned, in review of a previous series, that if the SLAP lesion was associated with a rotator cuff tear <50% of tendon thickness, there was an 89% reported rate of return to play, which was consistent with other studies looking at SLAP repair in the overhead athlete (S.O. Khan and F.H. Savoie unpublished data, 2007) [1, 3, 35].

Preoperative Planning

Preoperative radiographic evaluation in patients with signs and symptoms of internal impingement includes a standard AP, Grashey, scapular Y, and axillary lateral view of the affected shoulder. Radiographic findings associated with internal impingement include sclerotic changes of the greater tuberosity, posterior humeral head cysts, rounding of the posterior glenoid rim, and exostosis of the posterior-inferior glenoid rim, which has been described and termed a Bennett lesion [6]. This Bennett lesion has been reported in 22–60% of high-level baseball pitchers [36, 37]. Some authors have supported the idea that the Bennett lesion occurs secondary to traction stresses in the region of the tricep origin [38, 39]. Ferrari et al. [40] proposed that the calcific structures of the posterior-inferior glenoid are actually extraarticular calcifications based on their imaging studies. They suggested that the calcific changes may be due to repetitive traction of the posterior capsule and PIGHL during strenuous throwing motion [40].

MRI remains the gold standard for work-up of any overhead athlete with shoulder pain. Many authors suggest that the addition of intra-articular gadolinium to the MRI enhances the ability to identify labral tears and other lesions [41–45]. MRI findings in the painful overhead athlete include articular-sided partial thickness tears of the supraspinatus and/or infraspinatus, posterior-superior labral lesions, Bennett lesions, humeral head osteochondral cysts, and posterior glenoid lesions. The addition of the abduction external rotation (i.e., ABER) view has also been shown to enhance the diagnosis of internal impingement [46]. The authors believe that MRI with ABER view is the gold standard of imaging in the throwing athlete. Both radiographs and MRI should be used in conjunction with physical examination in order to establish a diagnosis of internal impingement and associated lesions to aid in preoperative planning.

Surgical treatment may involve repair of the superior labrum, release of the posterior-inferior glenohumeral ligament, debridement and possible repair of the anterior infraspinatus or posterior supraspinatus, and anterior capsular plication. All pathology must be anticipated based upon preoperative examination and radiographic findings. The following order of possible intra-articular repairs is recommended to ease visualization and prevent loss of access to various areas in the joint:

1. Repair of the peel-back SLAP lesion occurs first, as most PIGHL contractures contributing to change in total arc of motion (Tarm) have been resolved by preoperative rehabilitation.
2. Once the peel-back SLAP has been repaired, the arm is placed in the fully abducted and externally rotated position to check for continued internal impingement. If it still occurs at 90 degrees of ER or less, a selective PIGHL release may be performed.
3. If internal impingement is still occurring early in the ER arc at 90 degrees of abduction, then a PDS suture may be placed anteriorly at the 3 o'clock position with the arm hyper-externally rotated to decrease the amount of anterior laxity.

One should never tighten the anterior-inferior glenohumeral ligament nor should a subacromial decompression be performed in the throwing athlete except in rare instances.

Examination Under Anesthesia

The operative approach to patients with internal impingement and associated lesions should be pursued in a methodical fashion [6]. Surgical intervention should be directed toward specific pathologic lesions that are believed to correspond to the patients symptoms or are related to internal impingement [6].

Examination under anesthesia (EUA) is performed in the supine position with the scapula stabilized. The most important factor in the EUA is the total arc of motion. It should be equal or within 10 degrees side to side. The throwing shoulder should have more external rotation and less internal rotation than the opposite side, but the Tarm should be similar. Measurements using a special goniometer that incorporates a bubble level to provide a vertical reference point from which measurements are made. External rotation (ER) plus internal rotation (IR) equals Tarm. Internal rotation (nonthrowing shoulder) minus internal rotation (throwing shoulder) equals glenohumeral rotation deficit (GIRD). Examination under anesthesia will provide valuable information with regard to the posterior-inferior capsule internal rotation stretching response. Burkhart et al. [47] suggested anterior minicapsular plication if external rotation is greater than 130 degrees with the shoulder at 90 degrees of abduction or a persistent drive-through test after SLAP repair. This also suggests the importance of identifying subtle degrees of subluxation [6].

Positioning

A preoperative interscalene block is performed. Preoperative antibiotics are then administered. The patient is placed into the lateral decubitus position with a bean bag. This position affords excellent exposure to multiple aspects of the shoulder, especially the posterior-inferior joint. The arm is then secured to a rope and pulley system attached to 10 pounds of weight. We use a sterile stockinette and rope so we can remove the arm from traction while maintaining sterility to check motion and internal impingement [29].

Operative Technique

The standard posterior viewing portal is made first approximately 2 cm medial and 2 cm distal to the posterolateral corner of the acromion. The blunt trocar within the scope sheath is then directed through the incision anteriorly using the coracoid as a guide for the correct plane of the glenohumeral joint. The scope is then inserted, and a diagnostic arthroscopy is performed. An anterior working portal is then established using an outside-in technique localizing with an 18-gauge spinal needle to determine the appropriate trajectory [13]. Initial inspection involves the superior labrum and biceps anchor, rotator cuff insertion, posterior-inferior capsule, and anterior-inferior labrum and capsule. The joint is systematically inspected to ensure all areas relative to internal impingement are examined. Initial inspection from the posterior portal should focus on anterior labral pathology, laxity, and a positive drive-through sign. The drive-through sign is accomplished by sweeping the arthroscope superior to inferior between the glenoid and the humeral head to determine if the arthroscope can easily “drive through the joint” (Fig. 6.1a) [13]. Burkhart et al. [13] found this was associated with pseudolaxity associated with the SLAP lesions.

After placement of the first two portals, the joint is then thoroughly evaluated beginning with the anterior-inferior labrum, and the anterior capsule is evaluated for laxity. After this, attention is then turned to the superior labrum. An angled arthroscopic probe is used to test the stability of the superior labrum attachments to the glenoid. A normal sublabral sulcus is covered with articular cartilage and could be seen up to 5 mm medially beneath the labrum. If this sulcus is greater than 5 mm or labral attachments are frayed, there is likely a SLAP lesion. Next the biceps root is probed. If the biceps root is easily displaced medially onto the glenoid neck, this indicates an unstable biceps anchor. The peel-back test is then performed. While visualizing the posteriorsuperior labrum (Fig. 6.1b), the arm is removed from the traction cord and brought into 90-degree abduction and full external rotation position. Depending on the nature of the pathology, an anterior viewing portal, instead of a posterior viewing portal, may be used for viewing the peel-back maneuver (Fig. 6.1c) and to assess internal impingement (Fig. 6.1d). If there is a pathologic posterior SLAP lesion, this will cause the biceps/superior labrum complex to drop medially over the edge of the glenoid. If the scope is placed anteriorly, the scope is removed from the scope sheath. A switching stick is then placed through the scope sheath, and a cannula is then established over the switch-

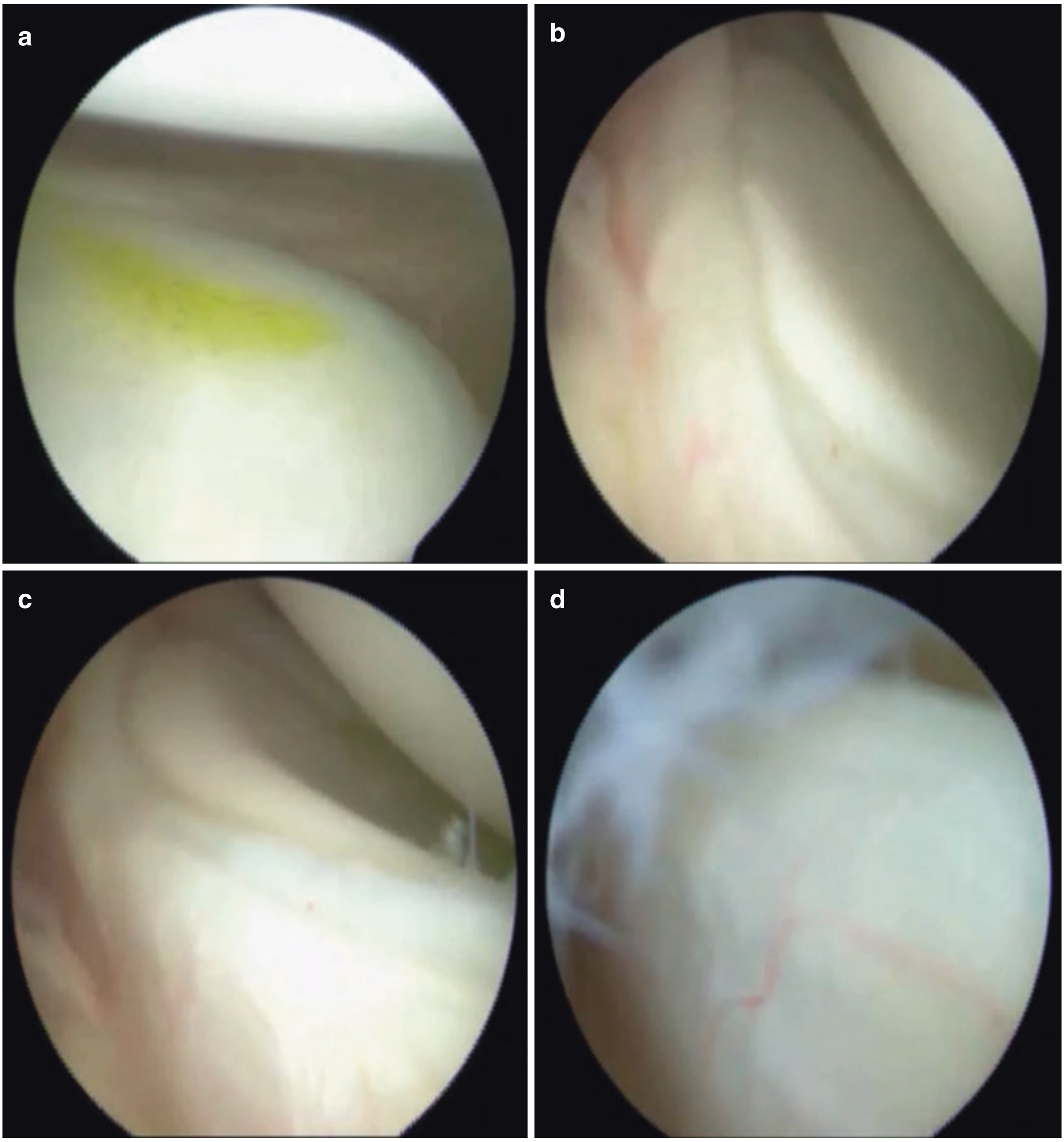

Fig. 6.1 (**a**–**d**) In this view from the posterior portal, the drive-through sign is demonstrated by easily sweeping the arthroscope from superior to inferior (**a**). While viewing the posterior-superior labrum (**b**), the arm is removed from traction and placed in the 90-degree abduction and full external rotation position. A positive peel-back can be seen with medial displacement of the bicep/superior labrum complex (**c**). With further external rotation, internal impingement with an articular-sided partial thickness rotator cuff tear is confirmed (**d**)

ing stick. The scope is then placed into the anterior cannula to visualize the posterior structures. An angled probe is then inserted, and the posterior-superior labrum is then probed, as well as the PIGHL. If there is posterior labral extension from the SLAP, the posterior-inferior glenoid is evaluated for a Bennett lesion through the labral tear. If not, a small incision may be made in the capsule to access the Bennett calcification. At this point, the arm is then removed from traction and placed in the 90-degree abducted and 90-degree externally rotated position to assess peel-back of the posterior-superior labrum and internal impingement (Fig. 6.2a–e). Next, the undersurface of the rotator cuff is evaluated for rotator cuff tears.

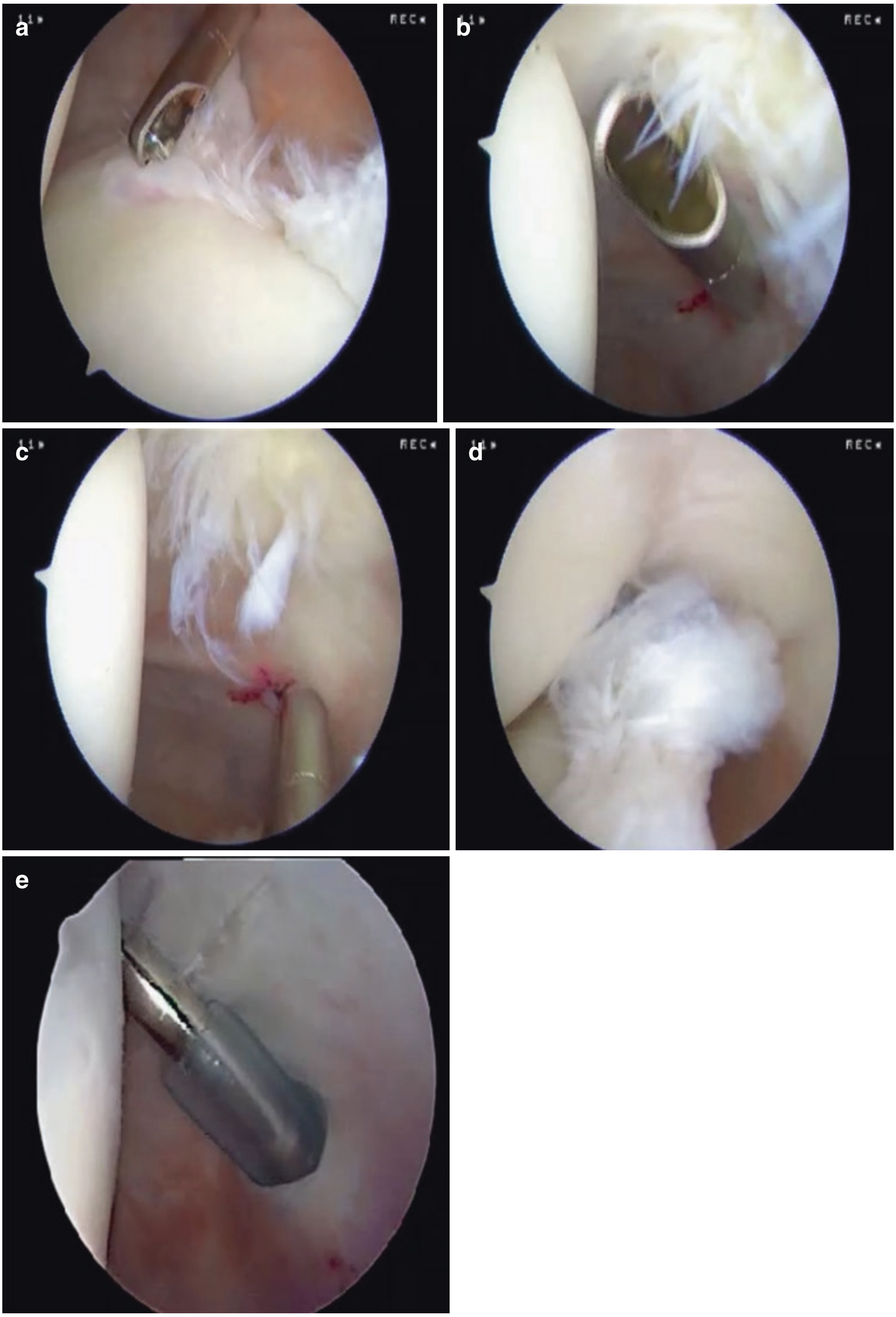

Fig. 6.2 (**a**–**e**) While viewing from the anterior portal, a frayed posterior-superior labrum visualized (**a**). The arthroscope is then redirected to view the rotator cuff and an associated partial thickness infraspinatus tear is noted (**b**, **c**). With the shaver removed, the arm is released from traction and placed in the 90-degree abduction and full external rotation position. Internal impingement of the rotator cuff on the posterior-superior labrum is appreciated (**d**). A cannula is placed in the posterior portal, and the infraspinatus tear is debrided with a motorized shaver (**e**)

SLAP Repair

While viewing from the anterior portal, the extent of the SLAP tear is probed. It is important to keep in mind that adequate preparation of the bone is necessary to achieve optimal healing. An arthroscopic rasp is used to release any remaining attachments of the torn posterior-superior labrum from the glenoid. A motorized burr with a protective hood is then used to prepare the lateral glenoid neck to a bleeding cortical bone. Limited use of suction is advised while using the burr to avoid accidental injury to the labrum. Debris is then removed with the shaver. We prefer to use the percutaneous portal of Wilmington for posterior glenoid anchor insertion. A spinal needle is used to establish this portal which is 1 cm anterior and 1 cm lateral to the posterolateral corner of the acromion. After this trajectory has been determined, this portal can be established in one of two ways: (1) One may elect to use a percutaneous kit, which involves shuttling a nitinol wire through a spinal needle followed by insertion of a cannulated switching stick. A 5 mm canula is then inserted over the switching stick. (2) Alternatively, one may elect to use a drill guide with the trocar directly following the trajectory of the needle. Once the portal is established, the drill guide is inserted. Starting at the most inferior aspect of the posterior labral pathology, a single-loaded or double-loaded suture anchor is placed (Fig. 6.3a–b). It is critical that the anchor be "cornered" on the glenoid neck-face junction to restore anatomic positioning of the labrum. Sutures are then passed according to surgeon's preference. We prefer using a penetrating suture retriever (Mitek Ideal Suture Grasper; Depuy Mitek Raynham, MA). The sutures are passed in a horizontal mattress configuration and retrieved through the labrum (Fig. 6.3c–d). This suture configuration is known to better recreate the normal superior labral anatomy [48]. It also avoids knot rotation and suture abrasion on the articular cartilage. Repair of the SLAP tear is typically performed using 1–2 anchors depending on whether a single- or double-loaded anchor is used. Regardless of surgeon preference, enough anchors must be used to eliminate the peel-back phenomenon. The 12 o'clock stitch is often placed using a spinal needle placed via Nevaiser's portal to shuttle a PDS that can be used to retrieve the sutures from the anchor. This is also an area where knotless suture anchors and suture tape can be used to excellent effect. In the overhead athlete, it is important to evaluate biceps mobility after anchor and suture placement to ensure adequate motion of the biceps tendon in the abduction external rotation position. Anchor placement anterior to the biceps tendon has been shown to increase the risk of biceps tethering and result in loss of external rotation [11]. The sutures are sequentially tied from inferior to superior using a modified Roeder knot (Fig. 6.3e). Alternatively, one may elect to perform a knotless SLAP repair. After the SLAP repair through the posterior portal, the superior labrum is probed to ensure a secure repair. The arm is again taken out of traction and put into the 90/90 position to visualize the peel-back (Fig. 6.3f). One should visualize complete obliteration of the peel-back phenomenon. One should also view the absence of internal impingement as the SLAP repair restores the capsular tension. If internal impingement still occurs, a reevaluation and possible release of the PIGHL may be indicated.

PIGHL Release

A posterior capsular release is rarely needed but may be indicated in stretch non-responders who have a continued deficit in Tarm despite adequate therapy. It is unusual for anyone less than the professional level to not respond to glenohumeral internal rotation stretching. The majority of athletes that do not respond tend to be older, elite pitchers who have been throwing for years [5]. In these non-responders, there will be a thickened PIGHL often more than 6 mm in thickness [29]. While viewing from the anterior portal, a hook tip cautery is brought in through the posterior portal to create a full thickness capsulotomy from the 6–7 or 5–6 position. It is vital in these athletes to keep the release to only the PIGHL, which is about 1 "hour" on the glenoid capsule. This capsulotomy is made just posterior to the labrum

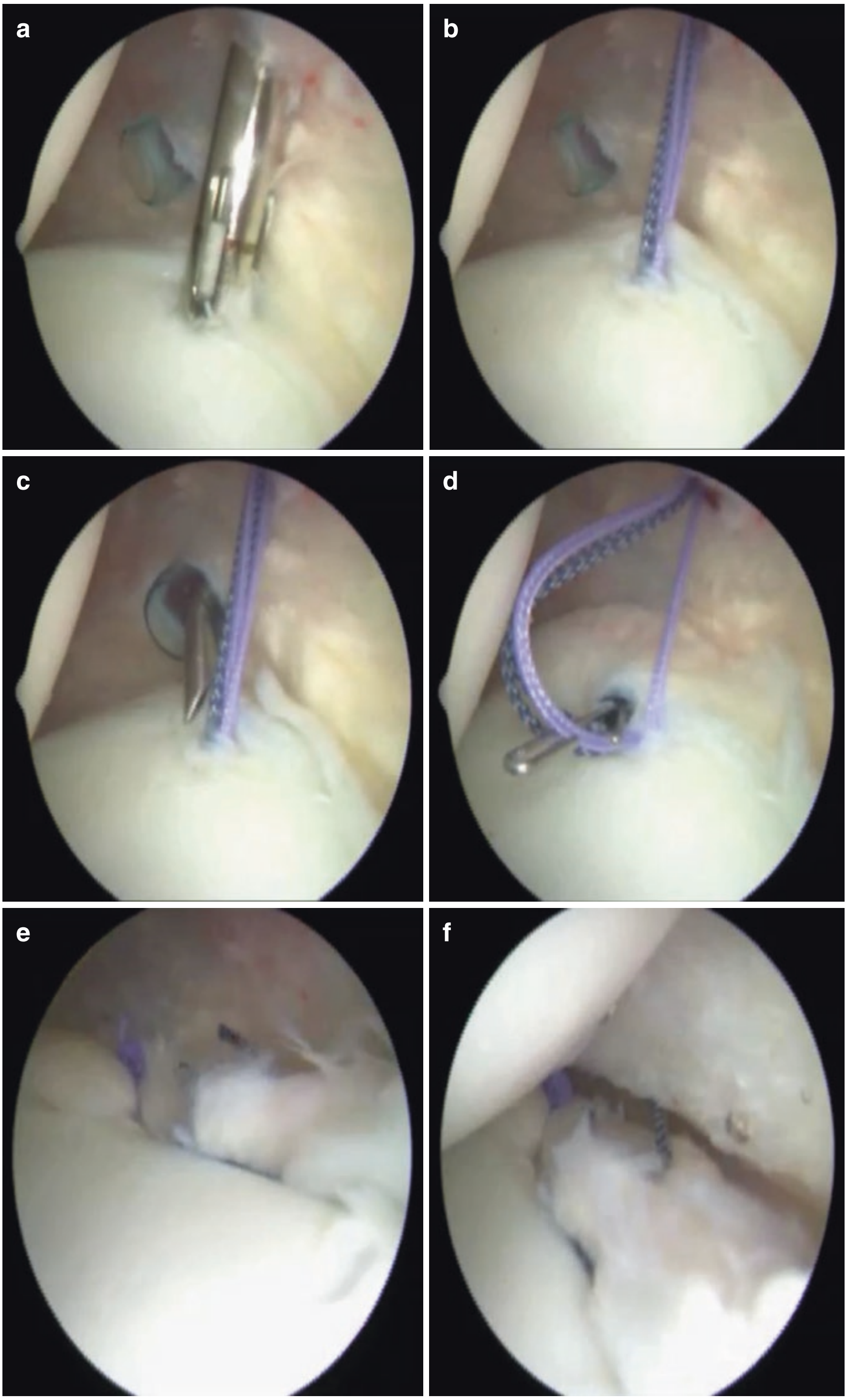

Fig. 6.3 (**a**–**f**) The portal of Wilmington is used for placement of the suture anchor in the appropriate position as seen in this view from the anterior portal (**a**). In this case, a double-loaded anchor is utilized (**b**). A penetrating suture retriever (**c**) is then used to pass the sutures in a horizontal mattress configuration (**d**). The sutures are then sequentially tied from inferior to superior (**e**). After repair, the arm is again removed from traction and placed in the abduction and full external rotation position to evaluate for peel-back. The absence of internal impingement and posterior-superior labral peel-back is confirmed (**f**)

with gentle sweeping motions to gradually divide the thickened capsular tissue. It is recommended to perform this aspect of the procedure without anesthetic paralysis, as muscular twitching will alert the surgeon that the electrocautery is near the axillary nerve. After this selective posterior-inferior capsulotomy, an immediate increase in glenohumeral internal rotation can be expected. It is important to begin an immediate postoperative internal rotation stretching program to prevent this capsulotomy gap from closing during the recovery [5].

Bony Glenoid Lesions

The treatment of a posterior-inferior glenoid exostosis, or a so-called Bennett lesion, has been somewhat controversial. Meister et al. [49] were the first to report on arthroscopic resection of Bennett lesions, but this technique was performed on only half of the 22 throwing athletes in which this finding was detected preoperatively. The authors concluded that this lesion was seen in conjunction with partial thickness tears of the rotator cuff and that debridement is appropriate when the lesion is larger than 100 mm^2 in total size. These patients underwent debridement of the rotator cuff and labral tear with resection of the Bennett lesion. At 6 years postoperatively, only 65% of the throwers returned to their premorbid level of throwing with a trend toward worse results in association with large osteophytes [49]. We recommend resection of the Bennett lesion only if the posterior labral extension of the SLAP tear extends inferiorly enough to allow adequate access to resect the lesion. This is performed prior to labral repair. We do not recommend resecting a Bennett lesion at the expense of taking down intact labrum.

Anterior Capsular Plication

The scope is then placed back into the posterior portal and the arm placed in the abducted and full externally rotated position to recheck for ongoing internal impingement. If it occurs at 90 degrees of external rotation, then additional surgery might be necessary. The extent of the capsular plication will be based on the amount of anterior capsule redundancy and is at the discretion of the surgeon. In this case less is more, and a single PDS suture between labrum and capsule is usually sufficient. This stitch is rarely necessary in most throwers. Care must be taken to avoid over tensioning the anterior capsule as this will restrict the full external rotation necessary in the overhead athlete. An arthroscopic rasp is first used to lightly abrade the capsule to aid in healing of the capsular plication. The anterior capsule is then plicated in an inferior to superior manner at about the 3 o'clock position, with minimal superior shift using #1 PDS sutures passed through a penetrating suture passer (Spectrum; ConMed, Largo, FL). A bite of redundant capsular tissue is taken laterally, and then the penetrator is advanced through the labrum at the glenoid-labral junction.

Rotator Cuff Tears

Several methods have been described in the surgical treatment of partial thickness rotator cuff tears in the overhead athlete. These include debridement alone, repair of delamination in situ without repairing to bone, and repair of the partial tear to bone with a suture anchor. Debridement of partial thickness rotator cuff tears alone has produced outcomes with return to throwing rates of up to 85%. However, these studies were limited by lower levels of evidence [14, 50]. There is also limited data on repair of delamination within the rotator cuff without repair to the bone, but early results have shown return to play rate of 89% (John Conway advocated this but has now abandoned it as ineffective). When a suture anchor was used to repair the partial thickness tear, the results have not been as favorable [34, 51]. This may suggest that anatomic restoration of the rotator cuff in the overhead athlete is related to poorer outcomes than debridement alone or non-anchored repairs. Van Kleunen et al. [1] reported on the treatment of rotator cuff tears in overhead athletes with internal impingement and found that the Kerlan-Jobe Orthopaedic Clinic (KJOC) overhead athlete shoulder and elbow score was worse in patients undergoing repair of the infraspinatus tear with a suture anchor compared to those in which a PDS suture was utilized. There was also a statistical difference in playing status, which was worse in the patients with anchor repairs. The authors felt that this free PDS repair technique minimizes the amount of iatrogenic trauma to the shoulder and lessens the detrimental effect on tendon repair. In supraspinatus and infraspinatus tears <50% tendon thickness, we recommend debridement alone. If the partial thickness tear is >50%, we recommend repair utilizing the free PDS suture technique. Most cases of supraspinatus partial articular-sided tears are <50%; therefore, debridement alone is usually sufficient. We also advocate the use of platelet-rich plasma (PRP) into the tear rather than attempt a repair to augment healing. Debridement of the partial articular-sided tear is performed.

Rehabilitation

The rehabilitation of the postsurgical throwing shoulder is discussed in other chapters. In our patients, we start active external rotation and scapular retraction exercises within the first week. Additional lower body and core conditioning is also started early postoperatively while protecting the SLAP repair. Once the labrum has healed, usually around 4–6 weeks, more aggressive stretching and exercises are initiated. A return to throwing program is started around 3–4 months and progressed as tolerated.

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7

Principles of Surgical Evaluation and Techniques for the Elbow in the Overhead Athlete

Michael C. Ciccotti and Steven B. Cohen

Introduction

Athletes in multitude of sports subject their upper extremity to incredible stresses, and overhead throwers in particular are at risk for injuries of the elbow. During the acceleration phase of throwing, the elbow reaches an angular velocity of 3000°/sec as it extends from 110° to 20° of flexion, corresponding to a 64 N/m valgus torque. The forces of the throwing motion result in a predictable pattern of stresses on the three compartments of the elbow: tensile stress on the medial or ulnohumeral compartment, compressive stress on the lateral or radiocapitellar compartment, and shear on the posterior compartment as the olecranon articulates with the olecranon fossa of the humerus. Although a variety of static and dynamic stabilizers resist these forces, the tremendous stresses of the throwing motion may result in either acute, catastrophic failure or chronic injury to any of these structures.

Appropriate orthopedic management of elbow pathologies in the athlete requires thoughtful history-taking, thorough physical examination, and well-selected diagnostic imaging. Obtaining a thorough history of an overhead athlete should include past injuries and treatments to the elbow as well as the remainder of the kinetic chain (shoulder, core, hips, and legs). Physical examination of such athletes should involve evaluation of the neck/cervical spine, both shoulder girdles (clavicles with associated joints, scapulae, and glenohumeral joints), both elbows, and the remainder of the kinetic chain, including inspection, palpation, range of motion, strength and sensation testing, as well as special provocative maneuvers. Diagnostic imaging may begin with plain radiographs but will often require advanced modalities such as ultrasound, computed tomography, and magnetic resonance imaging. This thorough evaluation will allow the clinician to confirm the suspected diagnosis as well as thoroughly exclude alternative or potential concomitant diagnoses. This chapter will review the surgical management of five elbow pathologies common among overhead throwing athletes: ulnar collateral ligament injury, medial elbow tendinopathy/epicondylitis, lateral elbow tendinopathy/epicondylitis, distal biceps injury, and distal triceps injury.

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Ulnar Collateral Ligament Injury

The valgus forces subjected to the elbow during the overhead throwing motion result in significant tensile stresses. The primary restraint against these stresses is the ulnar collateral ligament (UCL), specifically the anterior band which is subdivided into reciprocally tightening anterior and posterior bundles [1–3]. The valgus force experienced with each throw threatens to exceed the tensile strength, and both acute failure and chronic insufficiency may result. Indeed, numerous studies have documented the high incidence of these injuries, particularly in the throwing athlete, as well as an increase in both primary and revision UCL reconstructions [4–7].

History

The majority of throwers will describe insidious, vague medial elbow pain/discomfort/tightness accompanied by diminished velocity and control; however, some may complain of an acute injury with a "pop" [8]. These symptoms are typically most notable during the late cocking and acceleration phases of throwing. Pitchers, in particular, may complain of both decreased velocity and loss of control while throwing. All athletes should be questioned regarding sensory symptoms that might suggest ulnar nerve pathology. Difficulty gripping the ball and finishing pitches may indicate flexor-pronator involvement. Frank instability and/or debilitating weakness are rare with isolated UCL injury and typically occur only with significant concomitant injury.

Physical Exam

Physical examination of such athletes should involve evaluation of the neck/cervical spine, both shoulder girdles (clavicles with associated joints, scapulae, and glenohumeral joints), both elbows, and the remainder of the kinetic chain, including inspection, palpation, range of motion, strength and sensation testing, as well special provocative maneuvers. Inspection is often unremarkable. On palpation, tenderness should be maximal directly over the course of the UCL between the medial epicondyle of the humerus and the sublime tubercle of the ulna. Special provocative tests for UCL injury include the Milking Test and the Moving Valgus Stress Test, both of which elicit apprehension and pain localized to the ligament in the setting of injury. The Milking Test is performed by "milking" the thumb of the ipsilateral extremity while placing a valgus stress on the elbow as the ipsilateral shoulder is positioned in abduction and external rotation [9]. The Moving Valgus Stress Test similarly involves applying valgus stress to the medial elbow but as the elbow is flexed from 30 to 120 degrees, simulating the late cocking and acceleration phases of throwing [10]. Valgus stress will often elicit pain and apprehension in the setting of UCL injury; however, laxity may be more difficult to appreciate clinically. Neurologic evaluation should focus on ulnar nerve motor and sensory function distally in the hand as well as Tinel's sign along its course through the cubital tunnel. Finally, a thorough evaluation of the kinetic chain should be carried out, including examination of the shoulders, core, hips, and legs, as any deficiencies in the kinetic chain can worsen elbow symptoms in the throwing athlete [11–13].

Diagnostic Imaging

Although plain radiography should always be obtained for musculoskeletal complaints and may demonstrate calcifications, spurring, or loose bodies, UCL injury is best appreciated on advanced imaging such as stress ultrasound and MR arthrography [1, 14–28]. The T-sign is a common MRI finding and has been well described as suggestive of injury to the distal portion of the anterior band of the UCL at the sublime tubercle (Fig. 7.1). Joyner et al. have recently promulgated the first MR-based classification for UCL injury, which may prove to have prognostic value [29]. This classification describes MRA criteria for diagnosis of a spectrum of UCL injury from low-grade partial to high-grade partial, complete full thickness, and

Fig. 7.1 MRI demonstrating the radiographic "T-sign" consistent with UCL injury

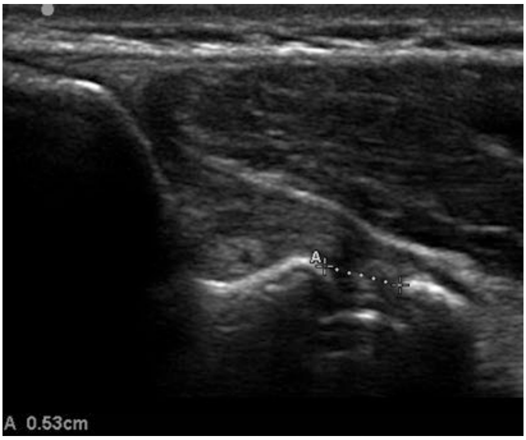

Fig. 7.2 Stress ultrasound demonstrating increased ulnohumeral joint gapping in the presence of a UCL injury

multiple site injury. Stress ultrasound provides a rapid, low-cost, non-radiating evaluation of the elbow with the dynamic application of valgus stress [1, 14, 15, 18, 19, 24]. Although overhead throwers demonstrate changes over time including ligament thickening and increasing ulnohumeral joint gapping under stress, thresholds for gapping consistent with injury have been established (Fig. 7.2). Most recently, Roedl et al. have evaluated the potential utility of combined ultrasound and MR arthrography in imaging of medial elbow pain in the throwing athlete. These authors identified statistically greater sensitivity, specificity, and accuracy for diagnosis of all medial elbow injuries with the combined use of ultrasound and MRA [30].

Management

In most patients, a multidisciplinary approach with nonoperative management including athletic trainers, therapists, strength and conditioning coaches, skills coaches, and physicians should be trialed initially. Such an approach includes rest, NSAIDs, optimization of the entire kinetic chain, and ultimately a graduated return to sporting activities such as a tossing/throwing program [11–13, 31]. Some recent data exists to suggest a potential benefit of orthobiologics (such as leukocyte-rich or leukocyte-poor platelet-rich plasma (PRP)) for athletes with UCL injury [32, 33].

Surgical management of UCL injury is indicated for (1) elite level throwers with complete tears, (2) throwers with a partial tear unresponsive to nonoperative management, and (3) and non-throwers with symptoms that disrupt activities of daily living and have similarly failed nonoperative management with the goal of restoring the stability of the anterior band of the UCL. Current surgical management ranges from repair with and without augmentation to reconstruction.

Preoperative planning in these patients should be focused on the necessity for treatment of concomitant pathology. Those athletes with significant flexor-pronator injury may require debridement and/or repair of the flexor-pronator origin. Athletes with persistent symptomatic ulnar nerve pathology may benefit from cubital tunnel decompression and, in the case of the throwing athlete, anterior subcutaneous ulnar nerve transposition with fascial sling or submuscular transposition. Those athletes with symptomatic posteromedial impingement and intra-articular loose bodies may require elbow arthroscopy for olecranon spur debridement/excision and loose body removal.

Today, while interest in repair has grown, reconstruction is the mainstay of treatment for UCL injury. A number of procedures for reconstruction have been described; however, the most popular are the modified Jobe and modified docking techniques, differing principally in the method of humeral attachment [42] [34]. Detachment of the flexor pronator has been abandoned in favor of a muscle-splitting approach, and obligatory transposition of the ulnar nerve, as originally described, is now typically performed only in the presence of persistent, preexisting symptoms. Primary repair with or without augmentation has been recently proposed in specific populations such as youth or adolescent throwers with limited throwing history and focal damage within the ligament or avulsion injury, without any chronic or degenerative changes in the remaining ligament [35, 36]. Postoperatively, the operative extremity is maintained in a splint for 7–10 days, after which the patient is transitioned to a hinged elbow brace. Elbow range of motion is progressively advanced, and upper extremity strengthening begins. Kinetic chain function is thoroughly evaluated and optimized throughout the postoperative rehabilitation [11–13, 31]. At 3–4 months postoperatively, the athlete may initiate swinging a bat, golf club, or racquet. A throwing program is initiated at 4–6 months [31]. Pitchers then progress through batting practice, simulated games, and rehabilitation starts. Pitch counts are closely monitored and progressed. Non-overhead throwing athletes may return to full activity at 8–12 months; however, full recovery in overhead throwing athletes may require 10–16 months. Surgical reconstruction utilizing any of a variety of techniques has demonstrated successful results, returning athletes to their pre-injury level of activity [32, 34, 37–44]. The results of repair, however, have traditionally been inferior to reconstruction, which provides well-documented, high rates of good-to-excellent results and return to play [36, 38, 39, 44, 45].

Posteromedial Impingement/Valgus Extension Overload Syndrome (VEO)

Posteromedial impingement and valgus extension overload syndrome (VEO) similarly result from the tremendous forces subjected to the elbow during the overhead throwing motion. Just at the tensile forces at the medial elbow produce UCL insufficiency and injury, the shear forces within the posterior elbow result in the pathology characteristic of posteromedial impingement, most commonly manifested as olecranon osteophytes [46]. Ciccotti et al. have shown that ulnohumeral laxity increases over time in professional baseball pitchers, even in the absence of ulnar collateral ligament rupture, which may subject the posterior compartment to increased shear with impingement of the olecranon on the medial wall of the olecranon fossa [18, 19, 24].

History

Athletes with posteromedial impingement/VEO describe posteromedial elbow pain during the follow-through and ball release phases of throwing when the elbow achieves near-full extension. This is in contrast to the complaint of medial elbow pain during the late cocking and early acceleration phases described above with UCL injury. Typically, onset of symptoms is insidious, without a single inciting event. History should include questioning to identify potential concomitant injuries such as UCL insufficiency, flexor-pronator tendinitis, and ulnar neuritis, as many athletes may present with a combination of pathology. Differential diagnosis should also include distal triceps pathology, which should be carefully distinguished from posteromedial impingement.

Physical Exam

In posteromedial impingement, tenderness is located in the posteromedial elbow and worsened with the Arm Bar Test [47]. This test is performed by abducting the shoulder, extending the elbow, pronating the forearm, and placing the patient's wrist on the examiner's shoulder, all while applying a hyperextension force on the posterior elbow. This forces the olecranon to impinge and should elicit the pain characteristic of the patient's complaint.

Diagnostic Imaging

Standard plain radiographs of the elbow may reveal posteromedial olecranon osteophytes and/or loose bodies. Advanced imaging, such as MR, may be unnecessary unless concomitant pathology such as UCL insufficiency is being considered. However, MRI may demonstrate posteromedial olecranon osteophyte formation, and bony edema may be present with impingement [48].

Management

Posteromedial impingement/VEO is initially managed with conservative measures including rest, judicious use of anti-inflammatories, and return to play via a graduated throwing program.

However, recalcitrant cases may require surgical intervention and can be managed by arthroscopy with osteophyte resection and/or loose body removal (Fig. 7.3). However, extreme care should be taken not to over-resect the olecranon. Multiple studies have demonstrated an increased risk of subsequent UCL injury with over-resection of the olecranon; Levin et al. have demonstrated that up to 8 mm may be safely resected [46, 49–51]. Although Andrews and Timmerman reported 92% good/excellent results at early follow-up after osteophyte resection for VEO, unfortunately, 41% developed recurrent medial elbow pain requiring surgery at 2–5 years, and 25% ultimately required UCL reconstruction, demonstrating the related nature of these pathologic entities [45, 46, 52].

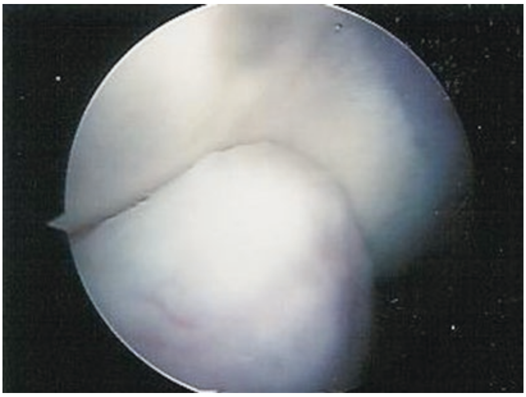

Fig. 7.3 Arthroscopic findings of posteromedial impingement/valgus extension overload syndrome characterized by olecranon osteophyte formation

Ulnar Neuritis

The ulnar nerve provides sensation to the small finger and ulnar aspect of the ring finger as well as motor innervation to the flexor carpi ulnaris (FCU), ulnar half of the flexor digitorum profundus (FDP), hypothenar eminence, and hand intrinsic musculature. Along its course from the upper arm to its terminal branches, the ulnar nerve is at risk of compression due to numerous adjacent structures including (1) the fascial hiatus in the medial intermuscular septum known as the "arcade of Struthers," (2) along the medial intermuscular septum of the brachium, (3) the medial head of the triceps, (4) within the cubital tunnel between Osborne's ligament and the underlying UCL, (5) in the presence of an accessory anconeus epitrochlearis muscle, (6) between the two heads of the FCU muscle, and (7) at the proximal edge of the FDS aponeurosis [53–57]. Additionally, the valgus stress placed upon the medial elbow during many overhead athletic activities can result in traction injury to the ulnar nerve. Whether due to traction or compression, ulnar neuritis can result in both pain and neurologic symptoms such a numbness and tingling, cold intolerance, and motor weakness. These symptoms may be further exacerbated by ulnar nerve instability with recurrent subluxation or dislocation of the nerve or from traction due to chronic UCL laxity [58].

History

Athletes with ulnar neuritis may have vague complaints of medial elbow pain which is not as easily localized as in other pathologies. Patients may describe numbness and tingling in their fourth and fifth digits. Pain is often dull, aching, or electric and may be present posterior to the medial epicondyle along the medial elbow, at the ulnar aspect of the wrist, or into the affected digits. Complaints are rarely associated with a particular phase of the throwing motion, unlike the alternative pathologies presented above.

Physical Exam

A careful neurologic examination is necessary to evaluate suspected ulnar neuritis. Physical exam should assess the ulnar nerve along its course, the presence and location of Tinel's sign, distal digital sensation, motor function of the hand intrinsics, and FDP to the small finger.

A positive elbow flexion test may be seen, in which the patient develops pain and paresthesias in the distribution of the ulnar nerve while holding the upper extremity in simultaneous shoulder abduction and external rotation, elbow flexion, forearm pronation, and wrist extension [59]. Those throwers with ulnar nerve subluxation most often have a palpable and visible subluxation of the ulnar nerve anteriorly with elbow flexion.

Diagnostic Imaging

Plain radiographs are often normal with an isolated diagnosis of ulnar neuritis; however, some chronic changes may be noted in long-time athletes. Advanced imaging such as MR is unnecessary for diagnosis but may be valuable to identify or rule out concomitant diagnoses such as UCL injury. However, electrodiagnostic testing should be obtained to document nerve conduction velocities bilaterally.

Management

Nonoperative treatment may involve rest, judicious use of anti-inflammatories, elbow padding, and nighttime splinting. With intractable symptoms despite nonoperative treatment or in the setting of physical examination/electrodiagnostic findings of severe disease, ulnar nerve neurolysis/decompression can be performed. In the throwing athlete, transposition (whether submuscular or subcutaneous) often accompanies decompression [60–62].

Lateral Tendinopathy

Frequently referred to as "tennis elbow," lateral epicondylitis has been recognized as a common source of elbow pain since the late 1800s [63, 64]. The common extensor origin attaches to the anterior border of the lateral epicondyle and is composed of the extensor digitorum communis (EDC), extensor carpi radialis longus (ECRL), and extensor carpi radialis brevis (ECRB). Lateral epicondylitis is a tendinopathy that characteristically affects the ECRB and is a result of microtearing of the tendinous origin with an incomplete healing response [65]. Histologic evaluation of this tissue has been classically described as "angiofibroblastic hyperplasia" without inflammatory features [66]. It is most common in the fourth through the sixth decades and occurs four to five times more frequently in males than female [67]. Although the condition is typically self-limited, the natural history is one of the slow improvements over 12 months in 80% of patients [68, 69].

History

Lateral epicondylitis is most typically characterized by insidious lateral elbow pain that is often accompanied by diminished grip strength. These symptoms may radiate down the affected arm and are often exacerbated by resisted wrist extension. The differential diagnosis includes peripheral nerve entrapment such as radial tunnel syndrome, which is characterized by sensory symptoms/paresthesias. A history of locking/clicking/catching should elicit suspicion for an intra-articular etiology of lateral elbow pain.

Physical Exam

Physical examination of lateral epicondylitis is notable for maximal tenderness 1–2 cm distal and anterior to the extensor origin on the lateral epicondyle that is worsened with resisted wrist and finger extension. A number of provocative tests have been described for lateral epicondylitis, the most common of which are Cozen's test, in which pain is reproduced with resisted wrist extension with the forearm in pronation and elbow extended, and Maudsley's test, in which pain at the ECRB origin is produced with resisted middle finger extension with pain [65]. Radial tunnel syndrome is distinguished from lateral epicondylitis by maximal tenderness more distal (approximately 3–4 cm distal to the epicondyle) as well as sensory signs such as positive Tinel's sign.

Diagnostic Imaging

Lateral epicondylitis is a clinical diagnosis often made on the basis of history and physical examination. Plain radiographs are typically negative but may demonstrate dystrophic calcification at the origin of the common extensor tendon in some cases. While not typically necessary for diagnosis and decision-making, MRI commonly demonstrates a thickened and edematous common extensor origin in approximately 90% of symptomatic patients [70–72].

Management

Given a natural history of improvement over 12–24 months, the mainstay of treatment for lateral epicondylitis is conservative, and an abundance of literature exists regarding the use of activity modification, physical therapy/stretching, NSAIDs, counterforce bracing, corticosteroid injections, orthobiologics such as PRP, acupuncture, etc. [65]. In particular, corticosteroid injections appear to provide short-term benefit without altering the natural history of lateral epicondylitis [73, 74]. In contrast to the short-term benefits of corticosteroids which modulate any inflammatory component, numerous orthobiologic injections have been proposed as a means of restoring the microenvironment of the tendon and stimulating tendon regeneration by introducing mesenchymal and hematopoietic stem cells, growth factors, and/or cytokines [75]. These include platelet-rich plasma (PRP), bone marrow aspiration concentrate (BMAC), autologous tenocyte injection (ATI), and adipose-derived mesenchymal stem cells. Although the underlying theory regarding these treatments is compelling, the literature has been mixed. Two randomized controlled trials have shown a significant medium-term benefit of PRP compared to corticosteroid injections; however, a systematic review has found evidence against its use in chronic lateral epicondylitis [76–78]. The literature on application of BMAC, ATI, and adipose-derived mesenchymal stem cells is far more limited, but some reports of success exist [79–82]. Although these options may be explored in recalcitrant cases, expectations should remain guarded until more robust data is available.

Surgical treatment has been reported in 4–8% of cases and is largely reserved for recalcitrant cases [83]. The most common technique has been modified from that described by Nirschl and Pettrone with a curvilinear incision made over the lateral epicondyle and incision between the ECRL and common extensor aponeurosis to expose the underlying ECRB origin [65, 84]. Excision of degenerative tissue within the ECRB tendon origin is undertaken, with creation of a bleeding bony bed and reapproximation of the adjacent, normal common extensor tissue. Some authors have advocated the arthroscopic management of lateral epicondylitis [85–87]. An arthroscopic procedure allows for intra-articular pathology to also be evaluated and addressed, and the deep surface of the ECRB tendon is evaluated and debrided following a partial capsulectomy. While no prospective randomized controlled trials directly comparing open and arthroscopic techniques have been performed, good results have been reported with no significant difference between the techniques on retrospective review [88, 89]. All arthroscopic procedures of the elbow can be technically challenging due to the proximity of surrounding neurovascular structures and the limited working space; surgeons should be prepared for a potentially steep learning curve if adopting this approach.

Medial Tendinopathy

Medial epicondylitis of the elbow, also known as "golfer's elbow," is less common than its lateral counterpart, accounting for 10–20% of all epicondylitis diagnoses [90, 91].

This disorder is a similar overuse syndrome of the flexor-pronator mass due to activities involving repetitive forearm pronation and wrist flexion and typically occurs in the fourth to sixth decades of life with an equal preponderance toward males and females [92–94].

Histologically, medial epicondylitis appears as an incomplete reparative process of the common flexor tendon with "angiofibroblastic hyperplasia" similar to that seen in lateral epicondylitis [66]. The common flexor tendon overlies the anterior bundle of the ulnar collateral ligament, and, with degeneration, increasing loads can be transferred to the underlying UCL placing that structure at risk of injury as well.

History

The history of medial epicondylitis is typically one of insidious pain localized to the medial epicondyle but may radiate into the forearm. Among overhead athletes such as throwers/pitchers, tennis players, and golfers, symptoms are typically maximal in the late cocking and early acceleration phases.

Physical Exam

Physical examination is typically positive for tenderness at or just distal to the medial epicondyle that may be accompanied by soft-tissue swelling. In cases of an acute tear of the flexor-pronator, there may be a palpable defect just distal to the medial epicondyle. Symptoms are exacerbated with resisted wrist flexion and forearm pronation. Careful physical examination, particularly in the throwing athlete, should exclude alternative causes of medial elbow symptoms including ulnar collateral ligament insufficiency, as described above, as well as ulnar neuritis.

Diagnostic Imaging

As with lateral epicondylitis, medial epicondylitis can often be diagnosed on the basis of history and physical examination alone. Plain radiographs are typically negative but may demonstrate calcifications with the common flexor tendon or the underlying anterior bundle of the UCL, particularly in long-time throwing athletes [91]. Ultrasonography has been shown to have sensitivity, specificity, and positive and negative predictive values all greater than 90% for diagnosing medial epicondylitis [95]. MRI is the gold standard for radiographic diagnosis of medial epicondylitis and is particularly valuable if there is concern for a tear of the flexor-pronator mass or to evaluate the integrity of the ulnar collateral ligament.

Management

Nonsurgical management utilizes the same strategies as for lateral epicondylitis and remains the mainstay of treatment, despite a lower efficacy than in lateral epicondylitis [96, 97]. In the case of an athlete sustaining an acute traumatic tear of the flexor-pronator tendon, early surgical intervention is indicated; otherwise, operative treatment is reserved for chronic cases with persistent symptoms despite extended nonoperative management. The orthobiologic treatments that have been advocated for lateral epicondylitis have also been proposed for the treatment of medial epicondylitis, but supporting data is less available given the relative infrequency of medial epicondylitis. Unfortunately, the benefits that have been seen in some studies on the use of PRP for lateral epicondylitis have not materialized when applied to medial epicondylitis [98].

Surgical technique commonly involves debridement of the pathologic tissue with care not to damage the underlying anterior band of the UCL. Incision is made at the medial epicondyle with immediate care to prevent injury to the medial antebrachial cutaneous nerve (MABC) but also the ulnar nerve and any of its motor branches to the flexor carpi ulnaris (FCU). If debridement is limited, side-to-side repair of the common flexor tendon may be possible, but with more extensive debridement, the tendon may require reattachment to the medial epicondyle in whole. Some surgeons advocate microfracture of the epicondyle prior to reattachment to provide a vascular bed [99].

Distal Biceps Tendon Injury

Distal biceps injuries almost exclusively affect males in the fifth to sixth decades of life although they have also been described in females [100–103]. The dominant elbow is involved in the vast majority of cases [104]. Prior anatomic studies have identified a hypovascular region in the distal biceps tendon which may become compressed or abraded in the space between the radius and ulna with repeated pronosupination [105]. This may ultimately contribute to failure as histologic examination of ruptured tendons has demonstrated a component of chronic tendinopathy [106]. Both smoking and prior steroid use have been identified as potential risk factors for distal biceps injury [104, 107].

History

Typically, biceps ruptures occur as traumatic events with a single eccentric contraction of the biceps. Patients describe an audible or palpable pop localized to the antecubital fossa and then a sensation of "giving way." This may be accompanied by severe pain. Over the following days, ecchymosis may develop in the antecubital fossa and may track both proximally and distally. In complete ruptures, the distal biceps tendon will migrate proximally with development of a visibly abnormal biceps contour, described as a "Popeye" deformity. This abnormal contour may be absent in partial ruptures or complete ruptures with an intact lacertus fibrosus. Patients may describe cramping within the biceps muscle belly. Acute injuries are typically considered to be those that have occurred within 4 weeks of presentation; chronic injuries present >4 weeks after injury.

Physical Exam

The biceps serves as the principal supinator of the forearm with maximum biomechanical advantage achieved as 90 degrees of elbow flexion [108, 109]. Supination strength should be assessed in comparison to the uninjured, contralateral extremity. Similarly, the biceps is a secondary elbow flexor, and flexion strength can be compared with the contralateral extremity. However, with an intact brachialis and brachioradialis providing primary and secondary flexion, respectively, a difference may be less appreciable than with evaluation of supination. The "hook test" has been described to assess continuity of the distal biceps tendon and is performed by positioning the elbow at 90 degrees of flexion with the forearm in full supination [110]. The examiner's finger is placed on the lateral edge of the antecubital fossa and directed medially in an attempt to "hook" underneath the biceps tendon as it passes distally to insert on the radial tuberosity.

Diagnostic Imaging

In complete ruptures with a compelling history and unequivocal physical exam, imaging may be unnecessary for diagnosis or decision-making. Plain radiographs are typically negative. MRI is the imaging modality of choice for confirming distal biceps rupture (Fig. 7.4). In cases of partial rupture or to determine the degree of retraction in chronic injuries, magnetic resonance imaging may be of particular use [111, 112].

Management

In the majority of patients, particularly athletes and those performing manual labor, surgical repair with anatomic reattachment of the distal biceps tendon to the radial tuberosity is indicated. These injuries are optimally managed in the acute phase before significant scarring occurs. In chronic injuries, biceps muscle atrophy occurs with additional retraction and scarring; tendon graft (hamstring

Fig. 7.4 MRI demonstrating a ruptured distal biceps tendon

autograft or hamstring/Achilles allograft) may be necessary in such cases if the remaining tendon cannot be mobilized to the radial tuberosity [113–116]. Both single- and two-incision techniques have been described and are commonly utilized for distal biceps repair. Both techniques utilize an approximately 3 cm transverse incision at or just distal to the elbow flexion crease. In cases of significant retraction, this incision can be extended proximally. The lateral antebrachial cutaneous nerve (LABC) must be identified and protected. Blunt dissection is utilized to identify the biceps tendon, which is mobilized and controlled with a heavy suture utilizing a suture-grasping technique such as a Krackow-style stitch. In a single-incision technique, dissection is carried down to the tuberosity with the forearm in full supination to protect the posterior interosseous nerve (PIN), and numerous fixation techniques have been described including suture anchors, interference screws, and suture buttons. In contrast, in the two-incision technique, a blunt curved clamp is passed just ulnar to the radial tuberosity through the interosseous membrane. A second incision is made over the tip of the clamp, and the radial tuberosity is exposed utilizing a muscle-splitting approach. In a two-incision technique, the forearm is pronated to protect the PIN. A bone trough is created in the tuberosity, and the biceps tendon then docked under direct visualization. Care must be taken to avoid contact with the ulna while traversing the interosseous space, and thorough irrigation of any debris is utilized to prevent synostosis formation. Postoperatively, patients are maintained initially in a well-padded splint at 90 degrees of elbow flexion and full forearm supination. Progressive range of motion is initiated at 1–2 weeks postoperatively with resumption of activities of daily living. Significant flexion/supination against resistance may be limited for 2–3 months postoperatively. Full strength and endurance may not be achieved until 3–6 months postoperatively [102].

Distal Triceps Tendon Injury

In the general population, distal triceps tendon injuries are rare; however, while still infrequent, they occur much more commonly in an athletic population such as professional American football players (NFL) [117–120]. A number of potential risk factors have been implicated including anabolic steroid use, endocrine disorders, metabolic bone disease, and chronic kidney disease [121–123].

History

Most triceps tendon injuries occur acutely as a fall on an outstretched arm resulting in an eccentric contraction of the triceps. Injuries have been described as a result of motor vehicle accidents, weight lifting, blocking in American football, and a direct blow to the tendon. Tears typically occur at the insertion into the olecranon, which blends broadly with the posterior capsule of the elbow joint, measuring on average 13.4 mm proximal to distal and 20.9 mm medial to lateral [124–128]. Injuries at the musculotendinous junction or within the muscle belly have been only rarely described.

Physical Exam

In acute injuries, there may be tenderness, swelling, and ecchymosis proximal to the olecranon. With a complete rupture, a defect will be palpable as the tendon retracts from its insertion on the olecranon. Partial tears may lack a palpable defect but will present with substantial pain with elbow extension. Completely tears will lack active extension against resistance; this should be tested overhead against gravity and resistance. With the assistance of gravity, the lateral triceps expansion and anconeus may substitute for the injured triceps when extending below the shoulder level [102]. A modification of the Thompson test used to evaluate for Achilles tendon injuries has also been described for the triceps. In this modified Thompson test, the patient is laid prone with the elbow flexed over the edge of the examination table; with an intact triceps tendon, squeezing the triceps muscle belly should elicit some elbow extension [129].

Diagnostic Imaging

As with distal biceps injury, the diagnosis and clinical decision-making can often be made on the basis of history and physical examination alone. However, plain radiographs may demonstrate a “fleck/flake” sign proximal to the olecranon as a thin shell of avulsed bone remains attached to the triceps tendon. Advanced modalities such as MRI and ultrasound can be helpful in more challenging cases where there is concern for partial tears.

Management

Management of distal triceps tendon injuries is dictated by patient needs and tear characteristics. Partial tears involving less than 50% of the tendon have been successfully treated nonoperatively [127]. Success of nonoperative management of distal triceps tears has also been demonstrated even among high-demand populations such as NFL players [118]. Nonoperative treatment consists of immobilization in 30 degrees of elbow flexion for 4 weeks prior to graduated return to activity [102].

In acute, complete tears with loss of active extension, surgical repair should be performed. When possible, repair should be performed within 2–3 weeks of injury as delayed repair with subsequent muscular atrophy, retraction, and scarring may require interposition soft-tissue graft and will likely result in greater persistent functional deficit. A number of repair techniques have been described, but regardless of which is used, a longitudinal incision is made over the olecranon with care in developing the medial skin flap to protect the ulnar nerve. The triceps stump should be mobilized, debrided to healthy tissue, and controlled with a locking nonabsorbable suture. The olecranon insertion should be cleared of soft tissue without decorticating the bone. Common repair techniques include transosseous cruciate drill tunnels, suture anchor repair, anatomic transosseous equivalent repair, and knotless anatomic footprint repair. Transosseous cruciate drill tunnels secure the tendon to the footprint by shuttling the locked suture ends through crossing bone tunnels in the olecranon and tying them down over the resulting bone bridge [126]. Standard suture anchor repair places two single-loaded suture anchors into the distal portion of the anatomic footprint site on the olecranon [124, 130]. Anatomic transosseous equivalent repair was described by Yeh et al. and utilizes loaded anchors in the proximal footprint and knotless anchors in the distal footprint to achieve a repair resembling a double-row rotator cuff repair [128]. Knotless anatomic footprint repair was described by Paci et al. and functionally acts as a tension band construct (Fig. 7.5). This technique has demonstrated biomechanical superiority in comparison to alternative repair techniques and is favored at the author’s institution [102].

Postoperatively, the elbow is immobilized in 30–45 degrees of flexion for 2 weeks and then braced prior to beginning active range of motion at 4–6 weeks postoperative. Strengthening is initiated at 8 weeks and return to many activities is not anticipated prior to 3 months. Weight lifting and high-demand athletics may require 4–6 months prior to full return.

Fig. 7.5 Completed knotless anatomic footprint repair of a rupture triceps tendon

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8

Principles of Rehabilitation in the Overhead Athlete

Kevin E. Wilk and Christopher A. Arrigo

The repetitive nature of overhead athletics causes the shoulder complex to be a common site of pathology. The shoulder is the most injured part of the body in professional, college, and high school baseball [1–44]. Shoulder injuries account for almost 30% of all disabled days in professional baseball players [1, 2]. Pitchers have a 34% greater shoulder injury rate than position players and are on the disabled list an average of just over 74 days per injury, a full 20 days longer than position players with shoulder pathology [1, 2]. Furthermore, the shoulder and elbow joints account for approximately 75% of the injuries to the baseball pitcher [1, 2].

The overhead athlete is dependent on dynamic stability during throwing to minimize the potential for injury. The "thrower's paradox" is the essential rehabilitation challenge in the overhead athlete – the shoulder must be loose enough to throw yet stable enough to prevent symptoms [5]. The inability to successfully balance this paradox is the primary reason overhead athletes are commonly injured and that their successful return to athletic participation can be difficult to manage.

The overhead throwing athlete exhibits very specific musculoskeletal adaptations because of throwing at a young age, as well as throwing frequently and at high volume. The glenohumeral joint motion adaptation most commonly seen in throwers is one of excessive throwing shoulder external rotation (ER) coupled with a loss of internal rotation (IR) when compared with the non-throwing shoulder [5–11]. The primary cause of these motion adaptations seen in shoulder ER and IR is an osseous adaptation of the humerus to throwing, resulting in humeral retroversion [12–19]. Other contributing factors to loss of glenohumeral joint IR include scapular position, posterior shoulder musculature tightness, and posterior capsular tightness. Thus, all these components need to be carefully evaluated and appropriately treated to successfully rehabilitate an overhead thrower. Postural adaptations to scapular position [20–22] and hip joint adaptations also result from repetitive throwing [23].

Key Rehabilitation Principles

The keys to the successful rehabilitation of the overhead athlete include proper shoulder mobility, a functionally efficient scapular base of support, dynamic stabilization, neuromuscular control via dynamic joint stability, and the integration of core, hip, and leg strength in the rehabilitation of the throwing athlete.

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Normalizing Shoulder Mobility

The restoration of full and complete overhead-specific motion is essential for the successful rehabilitation of the throwing athlete. Attention should be placed on restoring any loss of throwing-specific shoulder ER, IR, total rotational motion (TRM), flexion, and horizontal adduction, as losses of each of these movements have been linked to injury in the throwing athlete. The normal passive range of motion (PROM) values for each of these motions can be found in Table 8.1.

The overhead athlete commonly exhibits a significant loss of IR, commonly referred to as GIRD (gross internal rotation deficit) and defined as a loss of IR in the throwing shoulder of 17° or more when compared to the non-throwing arm [24, 25]. The loss of IR seen in throwers is most often due to osseous adaptation of the humerus and the glenoid fossa. In addition, the posterior soft tissue of the glenohumeral joint may contribute to the loss of IR. Therefore, a proper evaluation of the posterior capsule, posterior muscles, and scapular position is imperative. Scapular position such as an anterior tilt with protraction can cause a loss of glenohumeral IR.

TRM is the addition of the IR and ER measurements in 90° of shoulder abduction and is within 5° bilaterally in asymptomatic professional pitchers [5, 11]. A TRM greater than 5° increases the risk of shoulder injury in the overhead athlete [5, 11, 26]. Wilk et al. [27] reported TRM was a more significant risk factor for shoulder injuries than GIRD.

In addition, eccentric muscle contractions produce a rise in passive muscular tension and a loss of joint range of motion (ROM) resulting in generalized posterior muscular tightness and an acute loss of IR immediately after pitching [28].

Table 8.1 Passive range of motion throwing and non-throwing shoulder

Supine 90/90 position	Throwing shoulder	Non-throwing shoulder
ER	125–130°	100–120
IR	50–55°	60–65
TROM	180–185°	190–195
Horizontal adduction	40–45°	45–50
Flexion	178°	183°

Functional Scapular Base

Scapular stability, via muscular strength and neuromuscular control, provides a stable base of support critical for normal asymptomatic arm function in the overhead athlete [28–31]. The scapula is posteriorly tilted, elevated, and upwardly rotated via the force couples of the upper trapezius, serratus anterior, and lower trapezius placing it in an advantageous position for overhead athletics.

Throwers typically present with a rounded shoulders and forward head posture that is frequently associated with muscle weakness of the scapular retractors. The scapula on the throwing side often appears protracted, depressed, and anteriorly tilted in relationship to the contralateral scapula contributing further to a loss of glenohumeral joint IR [32, 33]. This abnormal scapular positioning is associated with pectoralis minor muscle tightness, coracoid pain, and lower trapezius muscle weakness in the overhead athlete. Pectoralis minor muscle tightness can lead to axillary artery occlusion accounting for symptoms of arm fatigue, pain, tenderness, and cyanosis [34–37]. Lower trapezius muscle weakness can lead to improper throwing mechanics placing the shoulder at risk due to a loss of controlling influence on scapular elevation and protraction during deceleration [38]. The evaluation of the scapulothoracic joint is critical in the successful treatment of the overhead athlete.

Kibler and Sciascia [19, 20] have developed the term scapular dyskinesis which refers to the abnormal movement of the scapulae and its relationship to injury. The scapula should be carefully evaluated and assessed for scapular dyskinesis and if present appropriately treated. Clinically, we frequently see a relationship between scapular dyskinesis and hip/core weakness. Therefore, the clinician should evaluate the entire kinetic chain to appropriately include all involved elements in the formulation of a proper rehabilitation program for the overhead athlete.

Neuromuscular Control and Dynamic Stability

Neuromuscular control plays a critical role in the generation of dynamic shoulder stability during overhead athletic activities controlling excessive humeral head translation [39, 40]. The combined effect of the rotator cuff musculature is a synergistic action that creates humeral head compression within the glenoid and counterbalances the shearing forces generated by the deltoid acting together in an agonist/antagonist relationship producing movement of the arm while stabilizing the glenohumeral joint [41]. Furthermore, the high forces and the extreme ranges of motion are controlled by the rotator cuff muscles stabilizing the humeral head on the glenoid fossa.

The centering of the humeral head within the glenoid fossa is enhanced by dynamic ligament tension produced through the anatomic blending of the rotator cuff tendons with the shoulder capsule which functionally tightens the glenohumeral capsular complex during overhead movement.

Core and Leg Strength

The linkage between the lower quarter, trunk, and upper extremity in the overhead athlete cannot be emphasized enough. A strong and properly functioning core, hips, and legs are required for symptom-free athletic performance. Exercises that focus on linking the shoulder and the lower quarter to facilitate the transfer of power from the lower extremity to the arm during throwing are critical in the rehabilitation process. Poor core, hip, and leg strength is often seen in adolescent- and preadolescent-aged athletes and requires the incorporation of posterior chain musculature strengthening and activation exercises during the rehabilitation process to address these deficits. Hip and core strengthening are critical and imperative to proper high-performance throwing. The hips and core should be evaluated in all overhead throwing athletes. Screening exam movements such as a single-leg squat, plank, and single-leg balance test can provide valuable information regarding the status of the overhead athlete's lower quarter and core musculature.

Multiphased Rehabilitation Program

Rehabilitation of the overhead throwing athlete involves a multiphased approach that is both progressive and sequential in nature and based on the findings identified during the physical examination with regard to the pathology present, specific anatomic structures involved, and the root cause of the condition. The four-phased rehabilitation program for the overhead athlete is outlined in Table 8.2. Each phase represents a progression where exercises become more aggressive and demanding, and the stresses applied to the shoulder joint gradually intensified.

Phase 1: Acute Phase

The reduction of pain and inflammation is critical to successful rehabilitation and restoration of normal rotator cuff recruitment in the overhead athlete. All appropriate combinations of interventions should be used to control acute symptoms because significant decreases in rotator cuff electromyography and ER force production are present in the painful shoulder [43]. We recommend the use of ice, class IV laser, electrical stimulation, and gentle motion to reduce pain and inflammation.

Shoulder motion and mobility deficits should be addressed via a combination of AAROM, PROM, manual stretches, and mobilization techniques. In addition, soft tissue techniques should be incorporated into the stretching program to help release and stretch tight or restricted tissues. It is common for the overhead athlete to display a loss of internal IR and horizontal adduction. Although the loss of glenohumeral IR can largely be attributed to osseous adaptations, other structures can contribute including tightness of the posterior rotator cuff, posterior capsule, and/or an anteriorly tilted scapula [5, 8, 13, 18, 44–46]. Each of these elements must be carefully assessed

Table 8.2 Rehabilitation of the overhead athlete

- Phase 1: Acute phase
  - Goals
    - 1. Diminish pain and inflammation
    - 2. Normalize motion
    - 3. Correct postural adaptations
    - 4. Restore proper muscle activation
    - 5. Normalize muscle balance
    - 6. Re-establish baseline dynamic joint stability
    - 7. Control functional stress/strain
  - Exercises and modalities
    - Cryotherapy, laser, iontophoresis, and/or electrical stimulation
    - Flexibility and stretching for posterior shoulder muscles to improve shoulder internal rotation and horizontal adduction
    - Rotator cuff strengthening (focus on external rotator muscles)
    - Scapular muscle strengthening (particularly the scapular retractors and depressors)
    - Dynamic stabilization exercises (rhythmic stabilization)
    - CKC/weight-bearing exercises
    - Proprioception training
    - Abstain from throwing, strenuous activity, and aggravating exercise
- Phase 2: Intermediate phase
  - Goals
    - Progress strengthening exercises
    - Restore muscular balance
    - Enhance dynamic stability
    - Control flexibility and stretches
  - Exercises and modalities
    - Continue stretching and flexibility (especially shoulder internal rotation and horizontal adduction)
    - Progress isotonic strengthening:
      - Complete shoulder program
      - Thrower’s Ten exercise program
    - Rhythmic stabilization drills
    - Initiate core lumbopelvic region strengthening program
    - Initiate leg lower extremity program
- Phase 3: Advanced strengthening phase
  - Goals
    - Aggressive strengthening
    - Progress neuromuscular control
    - Improve strength, power, and endurance
  - Exercises and modalities
    - Flexibility and stretching
    - Rhythmic stabilization drills
    - Advanced Thrower’s Ten exercise program
    - Initiate plyometric program
    - Initiate endurance drills
    - Initiate short-distance throwing program
- Phase 4: Return to activity phase
  - Goals
    - Progress to throwing program
    - Return to competitive throwing
    - Continue strengthening and flexibility drills
  - Exercises
    - Stretching and flexibility drills
    - Thrower’s Ten exercise program
    - Plyometric program
    - Progress interval throwing program to competitive throwing

Fig. 8.1 Modified sleeper stretch. The athlete is rotated slightly posterior to position the shoulder in the scapular plane as internal rotation is passively performed

to determine the causative dysfunctions to guide the appropriate treatment selection to restore IR.

An anteriorly tilted, protracted, and depressed scapular position is often seen on the throwing shoulder of the overhead athlete contributing to muscle weakness and/or inhibition of the scapular retractors. Poor muscle activation and weakness of the lower trapezius can result in improper scapular mechanics leading to shoulder symptoms and require focused strengthening to address. Pectoralis minor tightness can also be a contributing factor in abnormal scapular position and is best stretched with the scapula placed in a retracted and posteriorly tilted position in 90° of shoulder flexion as the humerus is placed in an abducted and ER position [47, 48].

The modified sleeper stretch (Fig. 8.1), modified cross-body horizontal adduction stretch (Fig. 8.2), and horizontal adduction stretch with concomitant IR (Fig. 8.3) are utilized to improve flexibility of the posterior shoulder musculature which can exhibit increased IR stiffness and

Fig. 8.2 Modified cross-body stretch. The athlete passively horizontally adducts the shoulder as the scapula is stabilized against the table, while external rotation is restricted with counterpressure of the opposite forearm

Fig. 8.3 Horizontal adduction with concomitant internal rotation. The clinician performs passive horizontal adduction while stabilizing the scapula as the athlete applies an internal rotation stretch

decreased ROM in the overhead athlete [49, 50]. Joint mobilizations are utilized if the posterior capsule is restricted and tight.

There is an association between scapular dyskinesis and hip abduction weakness, particularly in preadolescent and adolescent baseball players. This is often evident in poor ability to execute a single-leg squat test [51] (Fig. 8.4). Assessment should be made for side-to-side variations and any excessive lateral trunk displacement, valgus knee collapse, excessive hip flexion, lateral dropping of the pelvis, and/or lower extremity pain during the movement.

Fig. 8.4 Single-leg squat assessment. Bilateral comparison of position and movement of the trunk, pelvis, knee, and ankle

In this initial phase of rehabilitation, strengthening exercises are initiated to restore muscle balance and impede any further muscle atrophy, often beginning with pain-free, submaximal isometrics and progressing to isotonics as soon as symptoms permit [39, 40]. Manual rhythmic stabilization (RS) exercises are incorporated to facilitate a co-contraction of the ER and IR providing isometric stabilization of the glenohumeral joint to begin to address decreased proprioceptive sense typically seen following insult to the throwing shoulder. These drills can also be performed in the "balanced position" with the shoulder in approximately 100° of elevation and 10° of horizontal abduction providing for a centralized compression of the humeral head on the glenoid fossa in this position [52, 53]. The goal with RS exercises is to train the athlete to stabilize, controlling humeral head translation during applied movements. Manual resistance techniques can be utilized for the shoulder external and internal rotators and the scapulothoracic joint musculature. We routinely incorporate strengthening exercises for the following muscle groups in this initial phase: shoulder ER, scapular depressors, retractors, and protractors, hip abductors and external rotators, and the core.

The focus of this phase is to target muscles and muscle groups that are weak or exhibit poor activation. Core and hip complex exercises are employed in this phase for postural reeducation, stability, and mobility of the trunk, hips, and legs. Exercises such as single-leg squats, lateral slides, hip external rotation, and hip abduction exercises are all incorporated in the rehabilitation program during this initial phase of the process.

Phase 2: Intermediate Phase

The key element in this second phase of the rehabilitation process is the implementation of an EMG data-driven exercise program. The Thrower's Ten exercise program, designed by Wilk et al. [54], facilitates a progression to more aggressive isotonic strengthening activities emphasizing the restoration of muscle balance in the overhead athlete [55–63] (Table 8.3). The Thrower's Ten exercise program is most commonly initiated in the standing position for the glenohumeral joint exercises and prone for scapular exercises until good muscle activation is exhibited, after which the program is performed on a stability ball to maximally challenge the upper extremity and core musculature in tandem.

Neuromuscular control, stabilization drills, and manual resistance exercises are progressed into a full arc of the patient's available pain-free ROM to promote endurance training and dynamic stabilization of the rotator cuff.

Table 8.3 Thrower's Ten exercise program

External rotation at 0° abduction
Internal rotation at 0° abduction
Shoulder abduction to 90°
Scapular abduction, external rotation ("full cans")
Side-lying external rotation
Prone horizontal abduction
Prone horizontal abduction (full external rotation, 100° abduction)
Prone rowing
Prone rowing into external rotation
Modified robbery exercise
Reverse wall slides
Wall slides
Elbow flexion
Elbow extension
Wrist extension
Wrist flexion
Wrist supination
Wrist pronation

Fig. 8.5 Push-ups on an unstable surface with manual rhythmic stabilizations to facilitate dynamic stability for the shoulder and core musculature

Closed kinetic chain exercises are advanced to include proprioceptive drills, such as planks and table push-ups on a ball or tilt board (Fig. 8.5) as these have been shown to generate more upper and middle trapezius, as well as serratus anterior activity, when compared to performing a standard push-up exercise [64]. Stabilization drills should also be performed with the athlete's hand on a small ball against the wall as the clinician performs perturbation drills against the athlete's arm to produce an unstable surface demanding greater dynamic stabilization of the glenohumeral complex during exercise performance (Fig. 8.6).

Challenging exercises such as a side plank with superimposed shoulder ER are utilized to engage the hip abductors and shoulder muscles simultaneously, linking the shoulder joint complex with the core/lower extremity (Fig. 8.7). Additionally, prone full planks for time (1- to 2-minute holds), upper extremity wall slides for the serratus anterior, wall circles for lower trapezius activation, and anterior shoulder stretching should all be implemented along with specific exercises for lower trapezius activation and strengthening, including the modified robbery (Fig. 8.8), table press downs, and prone scapular lift-offs [65].

Fig. 8.6 Stabilization exercises as the athlete performs ball on the wall with the shoulder maintained at 90° abduction with manual perturbations

Fig. 8.7 Side plank with shoulder external rotation

Flexibility and ROM exercises for the shoulder joint complex are continued throughout this phase of treatment in conjunction with appropriate stretching for the trunk and lower quarter. Stabilization and strengthening exercises for the abdomen and lower back are also progressively advanced. Athletes are encouraged to perform lower extremity strengthening exercises and sport-specific conditioning activities beginning in this phase.

Phase 3: Advanced Strengthening Phase

This phase is designed to transition to aggressive strengthening exercises augmenting power and endurance, progress functional drills, and gradually reintroduce throwing. Full-shoulder ROM and flexibility should be maintained throughout this phase because failure to maintain motion and flexibility at this point is a potential pitfall that can result in recurrent symptoms.

Fig. 8.8 Modified robbery exercise for lower trapezius and posterior shoulder activation

Table 8.4 Advanced Thrower's Ten exercise program

Elastic tubing/band resistive exercises
External rotation at 0° abduction while seated on a stability ball[a]
Internal rotation at 0° abduction while seated on a stability ball[a]
Shoulder extensions seated on stability ball[b]
Lower trapezius isolation seated on stability ball[b]
High row into external rotation seated on stability ball[b]
Biceps curls/triceps extensions seated on stability ball[b]
Isotonic dumbell resistive exercises
Full can seated on stability ball[b]
Lateral raise to 90° seated on stability ball[b]
Prone Ts on stability ball[b]
Prone Ys on stability ball[b]
Prone row into external rotation on stability ball[b]
Side-lying external rotation
Wrist flexion/extension and supination/pronation

One set of 10–15 repetitions is performed for each movement successfully without breaks to complete one set

The goal is the ability to perform two full cycles of the entire program without pain, using the sound technique and no substitution

[a] Contralateral sustained hold performed during exercise

[b] Exercises are performed in three district continuous movements per exercise: bilateral active exercise, alternating reciprocal movement, and a sustained contralateral hold

Fig. 8.9 Advanced Thrower's Ten exercise performed on a stability ball to facilitate stabilization of the core musculature as rotator cuff, and scapular musculature endurance exercises are performed

Strengthening activities are advanced using the Advanced Thrower's Ten exercise program which incorporates high-level endurance in combination with alternating movement patterns to further challenge shoulder girdle neuromuscular control and facilitate the rotator cuff musculature via alternating dynamic movements with sustained hold drills [66] (Table 8.4). The incorporation of sustained holds challenges the athlete to maintain a set position, while the opposite extremity performs superimposed isotonic movements. Two sets are incorporated into each exercise, each following a sequential progression integrating bilateral isotonic movement and unilateral isotonic movement with contralateral sustained holds. The athlete can be instructed to perform these exercises on a stability ball to further challenge the core (Fig. 8.9), as well as with manual resistance drills to increase muscle excitation and promote endurance. Manual resistance provided by the clinician is employed to seated stability ball exercises to augment muscle excitation and improve endurance of the shoulder and core musculature.

Dynamic stabilization drills such as RS are performed in a functional throwing position. Ball throws against a wall to improve proprioception and neuromuscular control of the upper extremity are performed with stabilizing techniques that include perturbations and end-range stability with RS (Fig. 8.10), push-ups onto an unstable surface with perturbations, and ER tubing with concomitant manual resistance. In addition, these exercises can be performed on a physio ball to improve dynamic stabilization of the shoulder and trunk musculature. Advanced Thrower's Ten exercises including prone horizontal abduction and row into ER with sustained holds and alternating arm/sustained hold sequencing are initiated to challenge the endurance of the posterior rotator cuff, scapular musculature, lumbar extensors, gluteals, and hamstrings (Fig. 8.11). These types of exercises engage the posterior lower extremity chain and again link the upper extremity with the lower extremity. Side-lying ER, prone row, and prone horizontal abduction manual resistance of the shoulder joint complex is

Fig. 8.10 Ball throws into the wall with end-range rhythmic stabilization for neuromuscular control

utilized to promote increased muscular activity, neuromuscular control, and endurance which are essential in the force production for overhead athletes.

Plyometrics are initiated to further enhance dynamic joint stability and proprioception and gradually increase functional stress on the shoulder joint. Wilk et al. [67, 68] have described a plyometric program that systematically progresses stress on the throwing arm beginning with two-handed drills such as chest pass, side-to-side throws, side throws, and overhead soccer throws. Upon successful completion of these two-handed drills, the athlete can progress to one-handed drills such as standing one-handed throws, wall dribbles, and plyometric step and throws.

Muscle endurance training should be included in the rehabilitation program for every overhead athlete because muscle fatigue has been shown to decrease proprioception sense, alter biomechanics, and increase superior humeral head migration and is also the biggest predisposing factor to shoulder injury in Little League pitchers [69–72]. Endurance training exercises utilized include wall dribbles with a plyoball, wall arm circles, upper body cycle, and the Advanced Thrower's Ten exercise program. Furthermore, endurance exercises may include prone ball drops and side-lying external rotation ball flips. These drills are usually performed for time, such as a 30- or 45-second bouts of exercise.

Fig. 8.11 Advanced Thrower's Ten row into external rotation with sustained holds

An interval throwing program (ITP) is introduced during this phase of the program to gradually reintroduce the quantity, distance, intensity, and types of throws required to return the athlete to normal throwing [73]. The ITP is divided into two phases: phase I is a long-toss program for all athletes and phase II a progression to throwing from the mound for pitchers. Phase I is initiated at 45 feet (15 m) and is progressed with increasing distance as well as volume of throws. The athlete is instructed to use a crow-hop method for throwing to incorporate the trunk and lower extremities while throwing with a slight arc from each prescribed distance. Players can also begin a progressive hitting program that begins with swinging a light bat and progresses to hitting off a tee, then to soft toss, and finally batting practice.

During this advanced rehab phase, there exist some controversial topics such as weighted ball throws and extra long-distance throwing (such as 300–400 ft). Reinold et al. [75] reported a high injury rate with weighted ball throwing drills, with 25% of the subjects injuring themselves.

Fleisig et al. [76] noted high shoulder and elbow stresses with maximal distance throwing. This could be deleterious on the anterior shoulder as well as the medial elbow structures. We believe while these activities may be beneficial in increasing ball velocity, they should be approached with caution and only performed under the direct supervision of an expert in the field. Any pain in the elbow and/or shoulder area, the athlete should stop the drill and be assessed by the medical team.

Phase 4: Return to Throwing Phase

The final portion of the rehabilitation program is the continuation and advancement of the ITP systemically progressing the athlete back to unrestricted throwing. Position players progress from 45 feet (15 m) up to 180 feet (60 m), while pitchers advance to 120 feet (40 m) and then begin throwing from a windup on the level ground at 60 feet (20 m). Pitchers can begin phase II of the ITP upon successful completion of phase I, while position players begin position-specific fielding and throwing drills [73].

The athlete is instructed to continue with all previously described exercises and drills to continue upper extremity, core, and lower extremity strength, power, and endurance training. Additionally, the athlete should be educated on a year-round conditioning program including periodization of throwing and strength training activities to aid in the prevention of overtraining, initiating throwing when poorly conditioned, and properly prepare for the upcoming season [74].

Before the athlete is cleared to return to play or competition, a clinical and functional examination is performed to establish whether specific criteria can be successfully met to allow the athlete to return to unrestricted throwing (Table 8.5).

Table 8.5 Return to throwing criteria

Full non-painful ROM
Shoulder total ER/IR ROM in 90° of abduction within 5° of non-throwing shoulder
Shoulder horizontal adduction ≥40° on throwing shoulder
GIRD of <15°
Elbow and wrist PROM within normal limits
Shoulder, elbow, and wrist strength based on manual muscle test, hand held dynamometer, or isokinetic testing
ER/IR ratio, 72–76%
ER/ABD ratio, 68–73%
Throwing shoulder IR 115% > compared to non-throwing shoulder
Throwing shoulder ER 95% > compared to non-throwing shoulder
Throwing arm elbow flexion/extension 100–115% compared to non-throwing arm
Throwing arm wrist flexion/extension and forearm pronation/supination 100–115% compared to non-throwing arm
Satisfactory clinical exam
No pain, tenderness, or effusion
Negative instability testing: valgus stress and milking maneuver
Negative special test for other elbow or shoulder pathology
Physician clearance
Successful completion of all steps in the rehabilitation process
Satisfactory functional tests scores:
Prone ball drop test (throwing side ≥110% of the non-throwing side)
One-arm ball throws against the wall using 1 kg (2 pound) plyoball for 30 seconds without pain exhibiting the ability to maintain 90°/90° arm position without compensation
Throwing into plyoback rebounder with 1 pound plyoball for 30 seconds with no pain, normal mechanics (without substitution), and good control
Single-leg step down for 30 seconds controlling pelvis and lower extremity alignment for both sides (20 cm [8 in] step)
Minimum KJOC thrower's assessment score of 85

Abbreviations: *ABD* abduction, *ER* external rotation, *IR* internal rotation, *GIRD* glenohumeral internal rotation deficit, *KJOC* Kerlan-Jobe Orthopaedic Center

Summary

Repetitive throwing places increased stress and demand on the shoulder of the overhead athlete resulting in unique ROM, postural, strength, and joint laxity characteristics. An effective rehabilitation program for the overhead athlete is dependent on the accurate recognition of the underlying condition and pathology responsible for the symptoms. The program should focus on correcting the cause of the dysfunction and/or pain with focus on re-establishing full ROM and dynamic shoulder stability and implementing a progressive resistance exercise program to fully restore muscular strength, power, and endurance of the shoulder and scapular musculature. The program should incorporate exercises that link the upper extremity and the lower quarter including sport-specific drills and functional activities to facilitate a return to overhead sport. Additionally, proper throwing mechanics, utilization of pitch counts, appropriate rest, and proper off-season conditioning will help in decreasing the overall reinjury risk in the overhead throwing athlete.

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9

Criteria and Expectations for Return to Play

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Introduction

Clinically determining when an overhead athlete is ready to return to activity following musculoskeletal injury can be challenging. The difficulty exists for a number of reasons. First, the return to play (RTP) literature that has examined the rate of RTP for overhead athletes has reported a wide range of rates [1–12]. Differences in methodology across studies regarding patient demographics, diagnoses, treatment methods, and follow-up time and procedures have been so variable that it is difficult to provide an accurate estimate as to whether or not an overhead athlete will return to activity following a specific injury and/or intervention [13–15]. In specific examples, recent research has identified that return to preinjured levels of activity is challenging for different types of overhead athletes following shoulder surgery [13, 16] and can favor non-overhead athletes [13].

Second, the lack of standardized methodology is present not only in the aforementioned literature but also in clinical practice. In some instances, RTP or functional readiness has been determined by simply asking the patient 1 or more years following discharge from treatment if he or she returned to previous levels of activity [13]. This unfortunately creates the potential for recall bias that may influence the response. Yet others have attempted to utilize dynamic tasks that are more challenging than clinical measures to gauge a person's ability to physically function [17–26]. Some of these measures are reliable and objective while others have little to no evidence for their use in post-injurious scenarios. No matter the method, the intent of clinical decision-making is to obtain information that allows the clinician to make informed decisions regarding treatment, i.e., continue to treat, discharge from care, return to activity, or a combination of these. However, the lack of an identified "best" test or group of tests has created a gap in the clinical knowledge.

Finally, to varying degrees, these assessment techniques have been suggested to be helpful for assessing progress in the secure rehabilitation setting; however, it has been recognized that single component measurements do not necessarily translate to a patient's ability to perform a highly

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skilled dynamic task [27, 28]. In other words, an optimal clinical result on a physical performance measure in the rehabilitation setting may not translate to actual performance outcomes during sporting activities. For example, a baseball player's ability to elevate his arm to 160° in the sagittal plane, the ability to perform a high number of repetitions for an exercise, or his self-reported opinion about how well his arm feels on a particular day (measured via a patient-reported outcome measure) does not give any indication that he could effectively throw a ball overhead. In this clinical scenario, it would be imperative for a clinician to assess the player's ability to perform the task(s) necessary to participate in the sport of interest beyond standard single planar measurements and the athlete's individual opinion to justify allowing a return to sport participation. However, the issue at hand is that there is not a general physical performance measure or test that has been identified to be useful for a variety of shoulder injuries or across multiple sports.

Physical Performance Testing

Physical performance testing is a mechanism which incorporates task or sport-specific maneuvers into an isolated environment allowing the clinician to quantitatively and/or qualitatively assess a person's performance of a specific task [28]. Functional trials are assessments of skills designed to tax the local and global tissues involved in the initial injury. The trials provide the clinician with an observable depiction of integrated physical function and/or a quantifiable result (time, strength, endurance, distance thrown, etc.) allowing judgments to be made regarding the safe RTP to the sport of interest based on the performance of the task(s) [28]. However, a recent report suggested the label "physical performance measure" (PPM) is a more proper descriptor of such testing maneuvers because most "functional testing" maneuvers only assess one aspect of function (the physical aspect); therefore, broadly labeling a test simply as a measure of "function" may not be accurate [29].

Testing for the upper and lower extremity has been directed at identifying deficiencies during such maneuvers as the assessment of dynamic strength as well as unilateral and bilateral performance of the limb as a single unit [25, 28, 30]. Clinical decisions regarding injury risk or RTP are qualitatively and/or quantitatively based on an athlete's ability or inability to perform any of these maneuvers. However, unlike the lower extremity which has shown injury prediction and performance value with certain maneuvers [31, 32], the upper extremity does not have a popular or single "best" test to apply for examining upper extremity physical function. The complexity of the shoulder in both anatomical design and function as well as many different sports attributes may contribute to the difficulty in selecting a performance task for the upper extremity. Most clinicians err on the side of strength testing as strength is a basic physiological aspect of function, i.e., strength is foundational with adequate strength permitting fundamental tasks to be executed (arm elevation, stabilization, and gripping). Furthermore, strength can be easily and objectively assessed in the clinical setting [19, 33–38]. However, considering the body works as a unit [39–42], the utilization of testing maneuvers that can assess the ability of the body to work as integrated segments may provide more robust clinical information related to RTP.

It is important to note that although some generalized upper extremity PPMs have been described in the literature, most have only been investigated among non-injured subjects (Table 9.1) [17, 18, 22–26, 30, 43–47]. Therefore, the discriminatory ability of most existing maneuvers for differentiating between known groups (symptomatic versus asymptomatic, currently injured versus previously injured, or uninjured versus injured) is unknown. Although these details are lacking in the literature, it is possible that a more formalized algorithmic process may help clinicians make better return to play decisions for each individual patient.

Table 9.1 Psychometrics of upper extremity physical performance measures

Test	Normative data	Reliability[a] (ICC)	Standard error	Minimal detectable change
Push-up				
Negrete et al. 2010	Yes	0.96	1.0 repetition	2.0 repetitions
Baumgartner et al. 2002	Yes	0.96 (women) 0.98 (men)	1.0 repetition 2.0 repetitions	2.0 repetitions 5.0 repetitions
Y-balance test				
Gorman et al. 2010	Yes	0.92 (medial) 0.94 (superolateral) 0.95 (inferolateral)	3.0 cm 2.3 cm 2.2 cm	8.1 cm[b] 6.4 cm[b] 6.1 cm[b]
Westrick et al. 2012	No	0.91 (dom) 0.92 (non-dom)	2.4 cm (medial) 2.6 cm (superolateral) 3.7 cm (inferolateral) 2.2 cm (medial) 2.6 cm (superolateral) 3.4 cm (inferolateral)	6.6 cm[b] 7.2 cm[b] 10.3 cm[b] 6.1 cm[b] 7.2 cm[b] 9.5 cm[b]
Closed kinetic chain upper extremity stability test				
Goldbeck and Davies 2000	No	0.92	0.53 touches	1.0 touch
Ellenbecker et al. 2000	Yes	–	–	–
Rousch et al. 2007	Yes	–	–	–
Tucci et al. 2014	No	0.96 (sedentary male) 0.92 (sedentary female) 0.89 (active male) 0.85 (active female) 0.91 (impingement male) 0.93 (impingement female)	1.5 touches 2.0 touches 2.0 touches 3.0 touches 2.0 touches 2.0 touches	2.0 touches[b] 3.0 touches[b] 3.0 touches[b] 4.0 touches[b] 3.0 touches[b] 3.0 touches[b]
Sciascia and Uhl 2015	No	0.85 (asymptomatic) 0.86 (symptomatic)	2.0 touches 2.0 touches	4.0 touches 4.0 touches
Lee and Kim 2015	Yes	0.97	0.8 touches	2.0 touches
Posterior shoulder endurance test				
Moore et al. 2013	Yes	–	–	–
Shot put for distance (1 arm)				
Negrete et al. 2010	Yes	0.99	7 inches	17 inches
Pull-up				
Negrete et al. 2010	Yes	0.99	1 repetition	2 repetitions
One-arm hop test				
Falsone et al. 2002	No	0.81 (wrestlers) 0.78 (football)	0.2 seconds	0.5 seconds
Functional impairment test-hand and neck/shoulder/arm (FIT-HaNSA)				
MacDermid et al. 2007	Yes	0.98	–	–
Kumta et al. 2012	Yes	0.97 (patients) 0.91 (controls)	13 seconds 12 seconds	30 seconds 28 seconds

cm centimeters, *dom* dominant arm, *non-dom* non-dominant arm

[a] Test/retest reliability

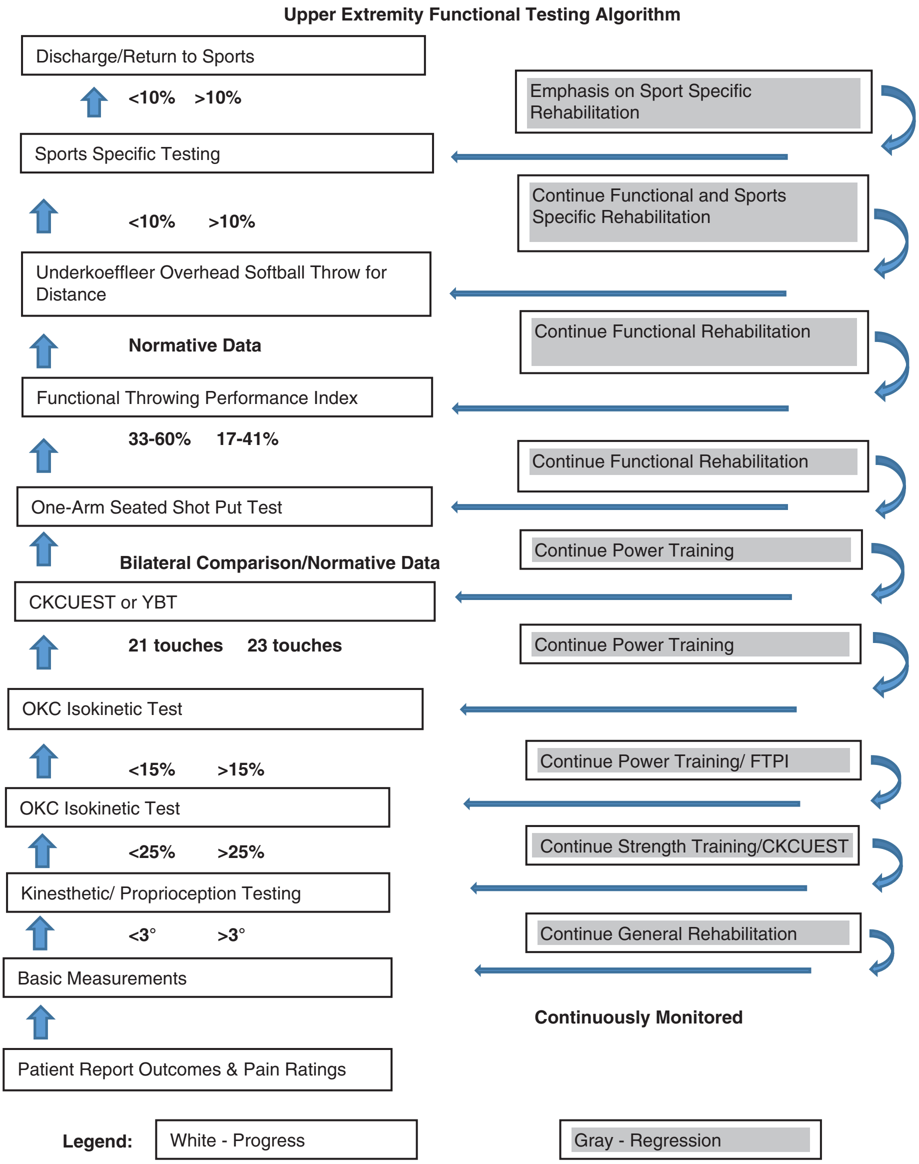
[b] Values calculated at 95% confidence level, all others calculated at 90% confidence level

Functional Testing Algorithm (FTA)

Davies and colleagues have previously described an FTA which is a criterion-based approach for clinical decision-making for RTP following a shoulder injury or surgery [48]. Using the FTA allows the clinician to follow steps to safely and efficiently return an athlete to full sport participation. The FTA begins with basic measurements that are representative of physical impairments in ROM, strength, endurance, and power. Without full ROM, strength, endurance and power, functional activity limitations will more than likely be present. When the basic physical impairments are resolved, testing can move into RTP PPMs. An athlete is progressed to the next step in the FTA if they are able to pass given criteria for each step. Each PPM level in the FTA places greater stress on the athlete's shoulder. This section will describe the FTA with an overhead athlete; however, not every test in every level will be needed with every athlete. For example, if the athlete is not a thrower, then the throwing specific PPMs should not be employed.

Basic Measures

Basic measurements in the FTA are classified as traditional clinical impairment measures and include time, soft tissue healing constraints, visual analog pain scales, anthropometric measures, active and passive ROM, and muscular strength. With these measures, if the athlete is within 10% bilateral comparisons, they are progressed to the next level of testing. If there is greater than a 10% bilateral difference, the athlete continues rehabilitation focused on those areas of weakness that were found in the FTA.



Multiple forms of proprioceptive testing can be used in the FTA. Sensorimotor testing such as proprioception testing or kinesthetic tests such as active joint replication testing, threshold to detect movement testing, and end-ROM testing reproduction can be performed. Probably the most common shoulder kinesthetic testing measure is that of active angular joint replication [49–55]. Testing active joint angular replication involves stimulation of both joint and muscle receptors and provides an assessment of the afferent pathway of the shoulder [50, 51]. Proprioception provides feedback from limbs to the central nervous system. Decrements in proprioception may increase the risk of shoulder injury [56]. To perform this test, the clinician, using a goniometer, places the athlete's shoulder in a particular angular position and allows the athlete to appreciate the spatial orientation of the arm. After a given period, the clinician moves the athlete's arm back to the neutral starting position. The athlete then attempts to replicate the position they were initially placed into as closely as possible. Davies and Hoffman examined active joint replication in eight positions, < and > 90° shoulder flexion and abduction, and external and internal rotation shoulder rotation < and > 45°. Normative data for 100 healthy males showed an average of the measurements to be 2.7° of error [55]. Other sources have reported errors of 3° for males and 4° for females [52]. Lephart and colleagues found that in healthy individuals there is no difference between dominant and non-dominant shoulders in regard to kinesthesia and joint position sense [53]. If errors greater than 3–4° exist in any of the tested positions, the focus of rehabilitation should continue on these basic measurements including joint proprioception and position sense. Once these values are improved to normal levels, the athlete can be progressed to the next test in the FTA. A key point for rehabilitation is that greater joint position sense errors have been identified to occur when patients are in supine positions [57]. This phenomenon suggests that performing shoulder exercises in supine positions may in fact exacerbate or contribute to proprioceptive deficits thus placing the patient at a functional disadvantage when attempting to obtain return to play.

Isolated open kinetic chain strength testing is needed to examine each muscle or group of muscles in the kinetic chain that may be responsible for the decreased functional level of the whole upper extremity. If only functional testing of gross functional movement patterns is performed, these weaknesses may be missed. Strength testing of shoulder and upper extremity muscles can be done with handheld dynamometry (HHD) (Figs. 9.1 and 9.2), isokinetic testing, or manual muscle testing. HHD is a quick and efficient manner to test shoulder strength. Turner et al. [58] determined the rank order of scapular muscles from strongest to weakest and also determined unilateral ratios. Scapular muscles rank ordered from strongest to weakest are upper trapezius (UT), serratus anterior (SA), middle trapezius (MT), rhomboids (R), and lower trapezius (LT). Unilateral ratios for scapular muscles include elevation/depression (UT/LT) = 2.62, protraction/retraction (SA/R) =1.45, and upward rotation/downward rotation (SA/MT) = 1.23.

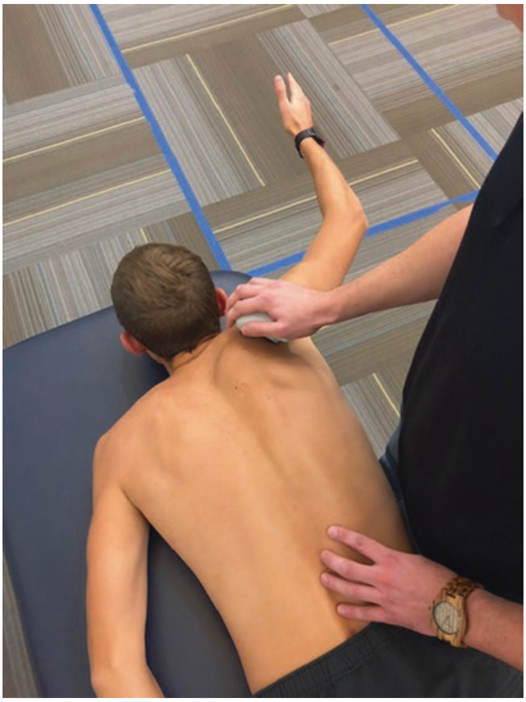


Fig. 9.1 Manual muscle testing example for the lower trapezius

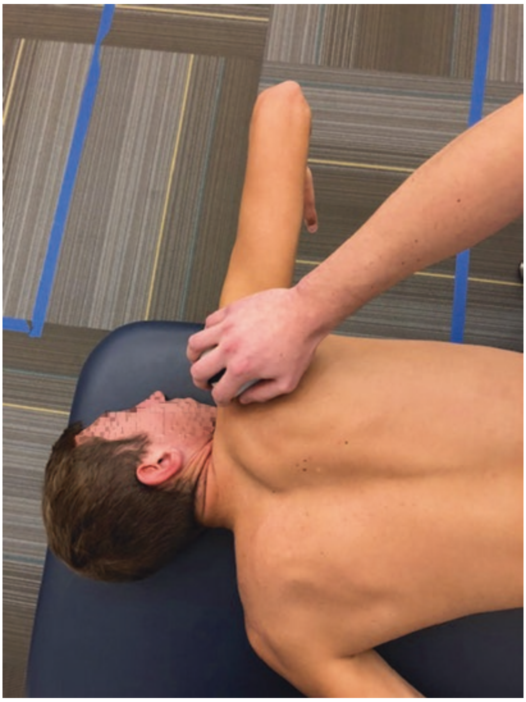


Fig. 9.2 Manual muscle testing example for the middle trapezius

To better test dynamic muscle function, an isokinetic test may be warranted. Isokinetic testing is considered the gold standard for strength testing and has also been shown to be correlated with PPMs [59–61]. Allometric scaling can be used to compare strength to bodyweight. When this is done, overhead athletes should have shoulder external to shoulder internal rotation ratios equal to 72–76%. Wilk and Andrews have described external shoulder rotator torque to bodyweight ratios of 18–23%, while internal shoulder rotator torque to bodyweight ratios should equal 26–32% [62, 63]. Isokinetic testing is done after generous warm-up as these types of tests are usually done at maximal effort. The authors recommend testing be performed for 5 maximal repetitions at velocities of 60/180/300 degrees per second.

The next set of PPMs closely replicate functional activities used in a variety of sports. Many of these tests have psychometric properties already determined in the sports rehabilitation literature which can aid a clinician in determining which tests are better suited for each individual athlete when using an FTA. a. Testing should consist of both open and closed kinetic chain functional movement patterns pending which is needed for the athlete's particular sport. For example, Negrete et al. [25] determined normative values for various upper extremity PPMs (modified pull-up, timed push-up, and seated shot put) and that the PPMs had excellent test/retest reliability (ICC $\geq$ 0.96). These tests were also found to be significantly correlated with the distance a softball was able to be thrown [26]. However, although these maneuvers assist with going beyond traditional clinical assessments, they may not provide a complete clinical picture about a person's ability to perform complex dynamic athletic tasks as their value for discriminating between individuals with and without injury has not been established.

Examples of tests that have attempted to examine aspects of physiological function beyond strength and power (i.e., stability) and are applicable to a variety of individuals would be the functional impairment test – hand and neck/shoulder/arm (FIT-HaNSA), upper quarter Y-balance test, and closed kinetic chain upper extremity stability test (CKCUEST) [17, 21, 22].

The FIT-HaNSA test is a timed, dynamic test that requires a patient to repetitively reach, grip, and maneuver objects at different heights [17]. The test primarily focuses on simultaneous postural control and reaching, simulating common activities of daily living, and repetitive manual labor (i.e., assembly line tasks). Excellent test/retest reliability has been reported in separate studies as well as the ability of the test to discriminate between subjects with and without subacromial impingement [17, 18]. Of concern is that the FIT-HaNSA may not be challenging enough for an athlete due to the lack of full body dynamics and maneuvering.

The Y-balance test is performed in a push-up position with the feet no more than 12 inches apart. The subject stabilizes his or her body with one hand while performing maximal effort reaches with the free hand in three directions (medial, superolateral, and inferolateral) (Figs. 9.3 and 9.4). The distance reached in each

Fig. 9.3 Medial reach of the upper quarter Y-balance test

Fig. 9.4 Superolateral reach of the upper quarter Y-balance test

direction is recorded. The CKCUEST is performed in a weight-bearing position requiring the individual to alternately lift and horizontally adduct one hand, touching the opposite hand in a repetitive sequence while maintaining a weight-bearing position similar to the extended position of a push-up (Figs. 9.5, 9.6 and 9.7). Normative values have been reported a variety of athletes and between males and females for both tests (Y-balance = 84–88% of limb length for males and 83–85% of limb length for females; CKCUEST = 19–30 touches for males and 16–20 touches for females) [21, 22, 45, 46]. Additionally, Westrick et al. determined that the Y-balance test is correlated with performance on the CKCUEST but noted that the two PPMs measure different aspects of upper extremity physical function

Fig. 9.5 Beginning position for the closed kinetic chain upper extremity stability test

Fig. 9.6 Initiation of movement for the closed kinetic chain upper extremity stability test

Fig. 9.7 Alternation of movement to opposite extremity for the closed kinetic chain upper extremity stability test

[23]. Furthermore, Rousch et al. tested collegiate baseball players and concluded that the CKCUEST appears to be a clinically useful test for upper extremity function [46].

While parameters of the Y-balance test have only been investigated in asymptomatic subjects, the CKCUEST has been found to be reliable in asymptomatic subjects as well as in subjects with subacromial impingement syndrome and chronic shoulder pain with test/retest reliability being reported as excellent [19–21, 47]. Although the test/retest reliability has been determined to be excellent, Tucci et al. found a distinct difference in the number of CKCUEST touches performed between subjects with (10–12 touches) and without (23–28 touches) subacromial impingement syndrome [20]. Sciascia and Uhl also found excellent test/retest reliability for the CKCUEST in subjects without shoulder symptoms and subjects with various diagnoses [51]. However, it was also determined that neither the CKCUEST nor traditional strength measures could differentiate between subjects with and without shoulder symptoms. However, in regard to injury prediction, Pontillo et al. identified an association between decreased performance during physical measures of function (which included the CKCUEST), assessed prior to a competitive season, and the occurrence of injury during the season [64]. It was found that the athletes who sustained an injury had a significantly lower number of touches during the CKCUEST compared to the athletes who did not sustain an injury. The findings of the study provide evidence that the CKCUEST may be a test maneuver which can identify a reduction in physiological function placing individuals at risk for future injury. The various findings between the studies are possibly due to subject differences. For example, the subacromial impingement syndrome subjects assessed by Tucci et al. were 24 years older on average compared to the healthy group which would suggest age may be a confounding factor [56]. The participants from Sciascia and Uhl had various diagnoses and none of the subjects were in active rehabilitation programs at the time of testing [51]. Finally, the subjects examined by Ponitillo et al. were primarily uninjured at the initial testing session [44]. However, a recent systematic review concluded that the CKCUEST has moderate evidence supporting its use as a clinical PPM [65].

The next set of PPMs are those that involve throwing or putting that can be tested initially bilaterally (Fig. 9.8) and then progressed to unilateral assessments (Fig. 9.9). The double arm seated chest pass was initially described by Cronin and Owen as a test to determine upper extremity power by using a 9 lbs netball [66]. There are no reliability or validity studies that have followed; therefore this bilateral test may be done simply to ensure that the athlete is able to perform power movements bilaterally before attempting to test more demanding unilateral assessments.

Gillespie et al. evaluated male athletes using the single-arm shot put test [67]. When compared against the bench press, the 8# medicine ball shot put test distance was found to be reliable and valid for both controlled and uncontrolled angles of release suggesting it is a good measure of

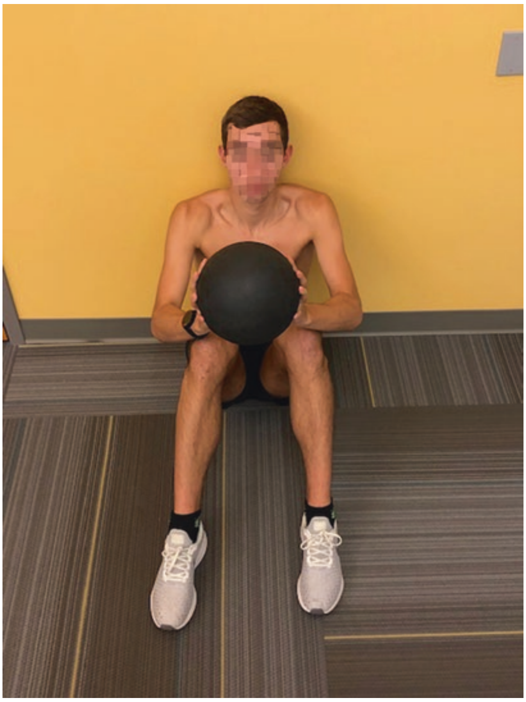


Fig. 9.8 Double arm shot press

Fig. 9.9 Single-arm shot press

upper extremity power, independent of throwing technique. Using a 6# medicine ball, Negrete et al. described normative data and performed reliability [25]. Reliability for the dominant arm was 0.988, while non-dominant arm was 0.97. Minimal detectable changes were also calculated and were found to be 17″ for the dominant arm and 18″ for the non-dominant arm. By using the single-arm tests, one can determine limb symmetry indexes similar to what is done when testing lower extremity function. Limbaugh has recently demonstrated that college baseball players demonstrate a combination of greater dominant arm side release height, anterior displacement, anterior velocity, vertical displacement, and vertical velocity which may demonstrate dominant to non-dominant side performance differences [68].

If the athlete being tested is involved in overhead throwing, two other more specific tests may be performed that more closely simulate the actual throwing motion. The Functional Throwing Performance Index (FTPI) and the Underkoeffler Overhead Throw for Distance. The FTPI was developed for indoor testing with limited space [55]. The dimensions of the FTPI are a line 15 feet from a wall, 1 foot square on the wall, and 4 feet high from the floor. The athlete performs four submaximal to maximal warm-ups (25/50/75/100%). The athlete then throws controlled maximum number of accurate throws for 30 seconds. The total number of throws are divided by the accurate number of throws and multiplied by 100 to calculate the FTPI. Reliability and validity data are not published on this test. The Underkoeffler Overhand Softball Throw for Distance is a maximal effort test using the entire upper extremity and trunk to propel a softball for distance. Four gradient submaximal to maximal warm-ups should be done prior to testing. This throwing test is done with a standard overhead throw and a crow hop. Three maximal effort tests are performed with the average of the three tests used as a score. ICCs above 0.90 have been described by Collins et al. [69].

The final stage of an FTA will consist of sport-specific testing that more closely mimic the movements and postures of the actual sports or recreational activity the athlete is returning to. These more sport-specific activities and movements may require a more qualitative assessment and analysis.

Recommendation

While an exact test cannot be universally advocated for assessing upper extremity function, any test employed should have the capacity to help clinicians discern an individual's ability to utilize the arm from different physiological perspectives. General tasks that assess repetitive reaching and maneuvering may provide useful information for nonathletic individuals. Overhead throwing tasks, which are complex by design, may allow clinicians to assess arm function from different perspectives but may be too specific to throwing athletes thus discriminating against overhead athletes who do not "throw" recovering from shoulder injury. Therefore, a variety of PPMs which could be applicable across a gamut of athletes would likely have more clinical usefulness, but the clinician should decide which PPM is most applicable to each individual patient.

Interval Progressions

Although not designed to serve as tests of physical function, a number of clinicians and authors have developed throwing and hitting programs based on clinical experience and/or data in order to facilitate RTP [70–75]. Data-based interval programs have been developed using volume of throws, swings, serves, etc. that the average overhead athlete performs during practices and/or games [70–72, 75]. The volume-based approach has been advocated because of its objective nature and because it allows an athlete to perform the required biomechanics for his or her sports in a repetitive but progressive fashion. This in theory could have motor control, sport specificity, and physiologic advantages. However, to date, no empirical study has been conducted that has determined the effectiveness of the data-based programs on RTP. This is not to say the programs should not be used in clinical practice but rather that evidence as it relates to the effect on RTP is absent.

Overhead sports can be characterized as being volume intensive and interval based. The repetitious nature of throwing, hitting, serving, and swimming has resulted in the occurrence of similar injuries (supraspinatus tendinopathy, tendonitis, impingement, and labral injury) across the various overhead sports [76–86]. Although there are sport-specific differences, in general, all overhead athletes need to be transitioned from the protective rehabilitation setting to the competitive setting with interval training programs possibly serving as the conduit between the two environments. Decision-making regarding which training regimens to implement and which progressions to follow should include sport position (if applicable), event specialty (i.e., specific strokes in swimming or field events in track), and physiologic requirements (anaerobic versus aerobic demands of sport/position). Based on the epidemiological evidence surrounding overhead sports, excessive volume and workload can lead to anatomical breakdowns [82, 87–91]. An interval training program is intended to be a progressive build of strength and endurance that allows the body to adapt and prepare for each sport's necessary demands. As a result, a primary focus of the RTP for overhead athletes is volume control and progression of intensity.

Recommendation

There is a lack of evidence either supporting or refuting interval programs as a testing method for determining RTP. However, the interval programs could serve as an adjunct, or more appropriately as a transition, between formal supervised rehabilitation and RTP. The programs seem to allow the clinician to progress the athlete based on volume and effect (i.e., soreness, stiffness, etc.) providing both quantitative and qualitative analysis of performance to occur. These analyses could serve as a precursor to more formalized physical performance testing.

Comprehensive Approach

Demonstrable physical performance is only one of many factors of physical function that must be considered when making a RTP decision [92, 93]. Matheson et al. noted that a systematic review of the RTP literature revealed 74% of articles routinely advocate addressing medical factors such as physical exam results, imaging, and functional tests as items of importance in the RTP process, yet only 26% considered other factors such as participation risk (type of sports, position, competitive level, etc.) or decision modifiers (timing and season, pressure from athlete, pressure from coach, masking injury, etc.) [93]. This does not suggest that medical factors do not have importance when determining readiness to return to activity, but it highlights the complexity of RTP decision-making.

Other authors have also suggested that a modification of the traditional method for measuring physical function be expanded beyond single component measures and should instead include a comprehensive approach where traditional clinical measures, patient-reported outcome (PRO) measures, and PPMs are collectively captured [29]. Moving to a comprehensive framework would potentially allow for a more thorough assessment of physical function by accounting for multiple components or dimensions that affect task execution [29, 94].

The effectiveness of this approach would be enhanced by obtaining information prior to injury to serve as baseline comparators in the event injury occurs in the future. This would be similar to head injury assessment models which attempt to establish physical and cognitive function prior to the occurrence of a head injury [95, 96]. Traditionally, clinical and self-reported measures of physical function are obtained at initial evaluation following injury and periodically throughout treatment to determine if progress is occurring. Ultimately, a final set of measurements helps determine if an appropriate amount of change occurred from initial evaluation to the cessation of rehabilitation in order for the clinician to make the decision to discharge the patient from care and RTP. For example, using the hypothetical case of an overhead athlete with a labral injury, the athlete is administered a shoulder-specific PRO to complete with the score, on a scale of 0–100 (low to high function), equaling a 30. After 3 weeks of treatment, the patient completes the same PRO, this time scoring an 80, with all impairments from the initial injury evaluation resolved per the clinical measures. The change of 50 points toward higher physical function and the elimination of the impairments lead the treating clinician to discharge the patient from care. However, the amount of change on the PRO, while rather large, is based on an initial measurement obtained at a time of dysfunction. It is unknown if the patient's actual pre-injured ability was greater than 80. Thus, the lack of a pre-injury assessment of physical function suggests that the goal of obtaining return to pre-injured activity levels has been at best assumed or based on less than concrete information [13]. This manner of assessment and reporting highlights a prominent gap in the literature that there is a lack of prospective information collected or utilized prior to the occurrence of injury and throughout the rehab continuum as the continuum technically begins prior to the injury occurring [13, 97].

However, to illustrate how the FTA could be applied clinically, consider Marci. Marci is a freshman collegiate middle distance swimmer whose primary events are the 200 and 500 meter freestyle. Marci was diagnosed with "swimmer's shoulder" by her team physician after complaining of anterior-lateral shoulder pain that consistently increased over the season eventually resulting in her missing practices due to pain and inability to wash her hair after practice. After 6 weeks of rest and rehabilitation, Marci reported she felt she was ready to return to the pool. Her patient-reported outcome measures suggest substantial improvement performing ADLs (i.e., washing her hair), her glenohumeral flexion and abduction within normal limits bilaterally, coordinated motion in her scapula, and improved core body strength. It was decided Marci could return to practice with the team based on results from the FTA.

Kinesthetic/proprioception testing can be tested in the standing, prone, and/or supine positions by asking the swimmer to place their shoulder in the scapular plane. The scapular plane is the optimal position of hand entry into the water following recovery phase during the freestyle stroke, so assessment of these motor control components in this anatomical position could provide an indication of the swimmer's ability to perform proper stroke technique. Based on recent research, it might be beneficial to first focus on regaining proprioception in a standing position, then progress to a prone or supine position. Because Marci's swimming training is interval based, her clinician decided to test her proprioception by first having her bring her arm to a target set at 120° from a standing position. (Intervals were chosen based on Marci's swimming ability and the time it takes her to complete her event. This will vary between swimmers, so clinicians should inquire about each swimmer's level of ability.) She performed this exercise utilizing 3 sets × 20 repetitions with 15 seconds rest between each set. The clinician's goal was to test Marci's proprioception but also to stress her body similar to a swim practice. Marci was able to touch the target 90% of the time indicating that she regained some of her neuromuscular control and could be further stressed by changing her body position. Recent research suggests shoulder elevation joint position sense is decreased lying supine compared with sitting upright [57]. In addition, research on swimmers following a 200-meter freestyle swim at race pace showed that joint position sense decreased compared with a rested control [98]. However, since improper stroke technique such as hand placement upon entry into the water has been linked with shoulder injuries in swimmers [99, 100], focus on proprioception in swimming-specific positions is important for injury prevention. Also, while the swimming results were attributed to post-race fatigue [98], from a rehabilitation standpoint, this information supports incorporating rehabilitation exercises in both the prone and supine position for swimmers, in addition to slowly building endurance to prevent fatigue [101]. Therefore, it is suggested kinesthetic testing be performed in a swimming-specific position in addition to the traditional standing position.

Marci's clinician had her perform a second proprioceptive test in a prone position. Prone was chosen since Marci's specialty stroke is freestyle, which is performed in a prone position. One of Marci's events is 200 freestyle which takes her 1:55. To replicate the specific demands of swimming, Marci performed 4 sets × 30 seconds of proprioceptive exercises with 15 seconds rest between each set. Marci was able to position her hand close to or on the target 90% of the time and was therefore progressed to the next level on the FTA, open chain isokinetic testing.

Isokinetic testing can be used to measure both strength and endurance. Due to various reports correlating posterior shoulder muscle dysfunction with pain and/or injury [87, 98, 102], recent swimming literature has emphasized the importance of posterior shoulder muscle endurance to prevent injuries in swimmers. Beach et al. [101] found decreased injuries in swimmers with greater external rotation/internal rotation endurance using isokinetic testing. However, inexpensive clinical maneuvers may be used in place of isokinetic testing since expense and availability of isokinetic devices may not allow the assessments to take place. Moore et al. [24] developed and utilized the posterior shoulder endurance test (PSET) to measure the endurance of the shoulder musculature in high school baseball players throughout a 20-week strength intervention. The PSET is performed by having the patient lay prone on a table with the arm perpendicular to the ground. Repetitions of horizontal abduction are performed at 90° and 135°. A metronome is used to control the speed of each repetition, and a number of repetitions are recorded until failure to reach the established arm position. Players were tested after 4, 8, and 20 weeks of training and found the players increased repetitions throughout the intervention. More recent literature using the PSET to measure posterior shoulder muscle fatigue and time to task failure showed healthy men's and women's muscles fatigued on average 68 seconds and 58 seconds, respectively [103]. The times that the muscles fatigued are similar to the amount of time it would take an average swimmer to perform 75–100 meters (or 3–4 lengths) of freestyle. While there is limited research on recovery time using the PSET, it might be beneficial to have the swimmer perform this test using an interval setup. For instance, the swimmer performs horizontal abduction sets for 1 minute with 15 seconds of rest 5 times. Marci's clinician decided to use the PSET to stress her endurance similarly to performing a 500-meter freestyle. This event takes Marci 5:20. To focus on this area, Marci performed two sets of 5 × 1 minute repositions of horizontal abduction with 10 seconds rest between each minute. During a swim practice, the swimmer may only have 5–15 seconds rest between each set, so these durations were chosen for Marci. Also, the PSET was performed bilaterally for side-to-side comparison of function. The first set was repetitions at 90° and the second set at 135°. The aim of performing sets with limited rest would be to determine if Marci's posterior shoulder muscles' endurance could withstand the demands of her race. Performing two sets in the different positions would also provide the clinician with information about Marci's ability to return to a practice setting where the endurance demands are greater than just one event swam during competition. Marci successfully completed the PSET with minimal discomfort and performed a consistent amount of repetitions through each minute. Compared bilaterally, Marci's scored within 1–2 repetitions. Using the PSET in an interval based setup provides the clinician with information about the swimmer's ability to stress the muscles commonly used during swimming in a sport-specific position and potentially a similar training technique.

Another method to test strength bilaterally is to use the CKCUEST. Hamman [104] suggests using the CKCUEST as a functional progression test for swimmers. For example, using information extracted from an existing clinical database of baseline physical performance measures and self-reported physical function from college athletes, 12 swimmers with a history of shoulder injury had 2 less touches during the CKCUEST compared to 39 swimmers with no history of shoulder injury [19]. This could suggest the uninjured swimmers were stronger than the injured group, or once injured, the tissue does not fully return to normal structure and function thus affecting physical task performance. The combination of closed and open chain movement needed to perform the CKCUEST could suggest greater stability of the glenohumeral joint and therefore less risk of future injury. Once the swimmer has progressed through the "power training" phase of the FTA, he or she should begin a controlled swimming protocol that focuses on proper stroke technique and limited yardage and intensity. Marci's clinician used the CKCUEST as a final measure of her shoulder function. During her initial evaluation, she was unable to perform the CKCUEST without pain; however, throughout her rehabilitation, she progressed to being able to perform the test pain-free. Marci's clinician decided to continue with using an interval-based testing situation. Since the CKCUEST is a power test, Marci's clinician asked her how long it would take her to do a 50-meter freestyle (this is considered an anaerobic, sprint event). Based on Marci's time of 28 seconds, her clinician had her perform the CKCUEST three times for 15 seconds each with 45 seconds rest between each trial. Shorter swims with increased rest are commonly used to build speed and power in the pool, so Marci's ability to perform 18–20 touches for each test consistently would provide her clinician with an indication of Marci's strength and power.

Marci's clinician focused on the components unique to swimming in her rehabilitation protocol, specifically interval training. Modifying how some the functional tests in the FTA are facilitated, such as testing proprioception using multiple sets and repetitions, may help the swimmer and clinician determine if and when the swimmer is ready to return to the water. Marci was able to demonstrate improvements in proprioception, endurance, strength, and power on land. The progression of the FTA suggests functional rehabilitation as the final progression. For Marci, this involves transition into practice in the pool. Once in the pool, functional rehabilitation will include drills that focus on stroke technique, kicking sets that improve both lower body and core strength, and interval training. (Interval training will begin with set amounts of rest and progress into time-based sets as Marci demonstrates proper stroke technique and reports she is pain-free.)

Recommendation

A comprehensive assessment and management approach is recommended for making RTP decision. Assess each component prior to the start of rehabilitation in order to improve the process by determining if any obstacles exist or which components beyond the impairments (if any) should be addressed. These same components should be measured at end of treatment to determine if patient should be discharged. However, determining if an athlete has returned to pre-injured levels of activity will not occur unless pre-injured baseline information has been obtained. Ideally, subjective assessments (patient expectation, perceived function/impairment), clinical assessments (impairment measures), environmental assessments (sport requirements, position, playing time, current team record), and physical performance assessments should be included for each patient.

Final Recommendations

- Until a maneuver or a select battery of maneuvers has been identified as having strong clinical utility, clinicians should select physical performance measures for the upper extremity based on individual patient needs. If the intent is to compare results between patients, maneuvers that are more general in nature and allow assessment of the body as a unit would be suggested. The use of an FTA may be helpful in determining a progression or hierarchy for testing sequencing.
- Interval throwing, hitting, serving, and swimming programs should be used as transition programs between the end of formal, supervised rehabilitation and RTP. At this time, they should not be used as clinical tests for deciding if RTP should occur.
- Based on an identified trend within the existing literature, determining if return to pre-injured levels of activity has occurred will be most accurate when baseline measures of pre-injured physical function have been obtained.

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10

Principles of Injury Risk Modification: Identification of Parameters, Techniques, and Results in the Overhead Athlete

Todd S. Ellenbecker

Range of Motion

A plethora of studies have been published on shoulder range of motion (ROM) in the overhead athlete [1–8]. Several fairly recent studies have not only published the traditional descriptive analyses but gone a step further and also provided critically important statistically and clinically relevant relationships between alterations and deficits in glenohumeral joint ROM and shoulder and elbow injury [4–7]. A recent meta-analysis and systematic review has also been published on glenohumeral internal rotation and upper extremity injury risk in the overhead athlete [9]. These studies highlight the importance of identifying alterations in normal sport-specific ROM through the use of clinically accurate methods.

Key Concepts for Accurately Measuring Shoulder ROM

Wilk et al. [10] have published a seminal article highlighting the importance of utilizing a specific repeatable consistent methodology to obtain glenohumeral joint internal and external rotation ROM. This article compared three methods of shoulder ROM measurement using a goniometer for internal and external rotation with 90° of glenohumeral joint abduction. This position of measurement is most recommended as it places the shoulder in the position most specific to the overhead throwing [11] and serving [12] position. The results of their study confirmed recommendations in prior descriptive studies [2, 13] that the use of scapular stabilization is of critical importance to gain accurate measures. The specific technique recommended by Wilk and others [2, 5, 13] is pictured in Fig. 10.1. This figure depicts the important application of scapular stabilization to both monitor and limit scapular compensation and contribution to glenohumeral internal rotation. The hand is placed such that the thumb of the examiner's hand is palpating the coracoid anteriorly, and the fingers of the corresponding

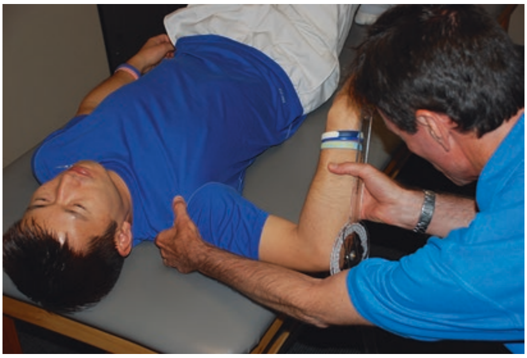

Fig. 10.1 Measurement technique for glenohumeral internal rotation in 90° of coronal plane abduction with scapular stabilization

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hand are placed posteriorly along the spine of the scapula. The examiner then uses the contralateral hand to rotate the shoulder to end range internal rotation until movement is initially sensed in the hand monitoring and stabilizing the scapula. This method not only produces joint-specific (glenohumeral) motion measurement but also has been shown to be reliable (ICC Intra-rater 0.62, ICC Inter-rater 0.43). The use of this method to monitor shoulder range of motion is an essentially important component of an injury risk modification program in the overhead thrower.

Additional ROM measurements have shown significance in injury risk in the overhead thrower. Shoulder flexion and external rotation ROM has also been implicated to elevate upper extremity injury in baseball pitchers [14]. This movement along with shoulder horizontal adduction (cross-arm adduction) has been measured and reported and is a component of posterior shoulder tightness implicated in modifying shoulder biomechanics and elevated injury risk [5]. The specific technique used for measuring shoulder cross-arm adduction has been well described in the literature [5, 15]. Again, the use of scapular stabilization is essential to better isolate glenohumeral joint motion and minimize the compensatory contribution from the scapula. Figure 10.2 shows the method recommended for measuring cross-arm adduction using the examiner's hand against the lateral border of the scapula in a consistent fashion. Additionally similar to the technique for shoulder internal and external rotation, gravity is used to determine the ROM end point without the use of examiner overpressure to ensure consistency.

Fig. 10.2 Cross-arm adduction range-of-motion measurement technique with scapular stabilization and digital inclinometer

Interpreting ROM Measures in Overhead Athletes

While the most important initial step in monitoring range of motion in the overhead athlete lies in the accurate and consistent measurement, the next critical step is having an understanding of the interpretation of the findings of those measurements for clinicians. Normative and descriptive data research form the basis of interpreting what at first may seem complexing ROM findings in the overhead athlete. The apparent loss of dominant arm internal rotation ROM called "glenohumeral internal rotation deficit" or GIRD was first reported and coined by Burkhart et al. [16, 17] and focused on the internal rotation component of shoulder rotation ROM. The evolution of the concept of GIRD, however, has led to a greater understanding and interpretation of this finding through the application of the total rotation ROM concept.

The total rotation ROM concept was originally reported by Wilk [6] and quickly regarded and published as a meaningful way to interpret shoulder ROM patterning in the overhead athlete. Descriptive studies have shown increases in shoulder external rotation on the dominant shoulder of overhead athletes and concomitant losses in internal rotation ROM on the dominant arm relative to the non-dominant arm for many years [1–7, 18, 20–24]. The total rotation ROM concept involves simply adding the ER and IR components of humeral rotation together to achieve a composite value or total rotation ROM. Research has consistently shown that total rotation ROM in the overhead throwing athlete (baseball and softball) is equal between extremities despite the dominant shoulder having significantly greater ER and less IR than the non-dominant arm [2, 5, 6, 23]. This concept can help guide interpretation of properly performed shoulder rotation ROM measures by clinicians who are performing both preventative evaluations and evaluations of injured athletes undergoing rehabilitation for shoulder and upper extremity injuries. In the study by Wilk et al. [7], pitchers whose bilateral TROM comparison was outside the 5° acceptable difference range exhibited a 2.5 times greater risk of sustaining a shoulder injury. Furthermore, 29 of the 37 injuries (78%) were sustained in throwers whose TROM was greater than 176°. Stretching to increase IR PROM, thereby treating the GIRD, may result in an increase of TROM greater than 176° or outside the 5° acceptable window compared to the contralateral shoulder. This may lead to an increased risk of injury due to the increased demands on the dynamic and static stabilizers surrounding the shoulder joint.

Another important risk modification factor to consider is external rotation deficiency. External rotation deficiency (ERD) is defined as the difference between ER of the throwing shoulder and the non-throwing shoulder of less than 5°. Therefore, when comparing a players' ER PROM from side to side, it would be expected to see an ER difference of greater than 5°, indicating that a player's ER gain on his throwing side is significant enough to contribute to the demands of throwing, specifically during the late-cocking phase of the pitching motion. A pitcher with ER side-to-side differences that are <5° may impart increased stresses on the static stabilizers, thereby contributing to an increased risk of injury over the career of the athlete (4,7].

Therefore as the research by Wilk and others [2, 5–7, 18, 19, 21] highlights, careful and systematic analysis of the results of shoulder range of motion measures in the dominant and nondominant shoulders is needed to guide the clinician as to whether specific interventions are needed to address real or only apparent losses of ROM in the overhead athlete.

To highlight and further develop this concept, the example contained in Table 10.1 shows two throwing athletes presenting with particular ROM patterns with differing clinical interpretations guiding interventions that would occur and be recommended in preventative and rehabilitative settings.

The two player examples in Table 10.1 show real-world overhead athlete presentations clinically encountered. The key lies in the interpretation. Current recommendations for player A with obvious decreases in dominant arm shoulder IR (20° loss) but EQUAL total rotation ROM are for no intervention(s) to be provided to change or alter ROM. This is due to the consistent finding that healthy uninjured throwing athletes (little league through professional) have symmetrical total rotation ROM patterns despite having ER and IR asymmetries [2, 5, 6, 21–23]. Manske et al. [22] have termed this condition as A-GIRD (anatomic GIRD) indicating anatomic adaptations in the overhead athlete to the throwing motion to increase ER at the expense of IR resulting in equal total rotation ROM. Tyler et al. [24] published the results of a prospective study following high school pitchers who had preseason ROM and strength measured. Their study actually showed that throwers who did NOT have IR ROM loss were more often injured than pitchers with IR ROM loss. Their rationale for this finding is that high school pitchers who do not present with some IR ROM loss similar to the example of player A listed above may not have pitched enough to gain this inherent adaptation and hence may be more at risk for injury. This further supports the opinion of the authors in the Manske et al. [22] paper stating that A-GIRD is actually expected or "normal" in a conditioned throwing or overhead athlete. Table 10.1 also contains the example of Player B, who not only has a significant clinical difference in internal rotation (35° loss) but also a loss of total rotation ROM by 15°. This has been termed P-GIRD (pathological GIRD) and is present when there is a significant loss of both internal rotation ROM and total rotation ROM. The presence of P-GIRD would result

Table 10.1 Glenohumeral joint rotational ROM in two throwing athlete's shoulders

	Player A		Player B	
	Dom arm	NonDom arm	Dom arm	NonDom arm
ER 90 ABD	120	100	120	100
IR 90 ABD	30	50	15	50
Total rotation	150	150	135	150

in the clinical application of specific interventions to address focused internal rotation ROM loss. Wilk et al. [7] have shown that decreases in as little as 5° of total rotation ROM can increase shoulder injury or surgery by 4–5 times.

It is important to note that descriptive data provides important guidance toward the identification of thresholds for ROM loss before interventions are provided. Ellenbecker et al. [1, 2, 19, 20] have published data in elite level junior tennis players and in professional tennis players and found consistent glenohumeral joint rotational patterns when comparing the dominant and non-dominant shoulder. In contrast to what has consistently been reported in baseball and softball players, elite level tennis players show 5–8° of both dominant arm total rotation and internal rotation ROM loss compared to the non-dominant extremity. Therefore, when evaluating elite level tennis players, it is recommended that ROM interventions be applied when greater than 5–8° losses are encountered in IR and total rotation ROM, unlike in baseball and softball players where symmetrical total rotation ROM is expected and striven for through interventions. Unlike shoulder rotation ROM profiles in baseball players where symmetrical total rotation ROM patterns are expected and commonplace, it is not expected or required that elite level tennis players have bilaterally symmetric shoulder total rotation ROM.

Camp et al. [14] studied 81 major league pitchers and measure shoulder rotational ROM in reference to shoulder and elbow injuries in subsequent seasons. They found no relationship between shoulder rotation ROM and shoulder injury but significant relationship between decreases in shoulder forward flexion and external rotation in the dominant shoulder and elbow injury. For every degree or % loss of forward flexion and ER ROM, this study demonstrated increased injury risk for a throwing-related elbow injury. Wilk et al. [7] also reported increased risk of elbow injury in professional baseball pitchers. They reported shoulder forward flexion ROM losses of greater than 5° compared to the non-dominant extremity as increasing risk of elbow injury 2.8 times, while loss of total rotation ROM greater than 5° as elevating elbow injury risk 2.6 times. Both Camp et al. [14] and Wilk et al. [7] did not find IR ROM loss to be a risk factor for shoulder or elbow injury. These studies highlight the need to expand the clinician's scope of surveillance beyond simply looking at unilateral internal rotation ROM loss and include total shoulder rotation and other measures in the preventative evaluation.

Injury risk modification through repeated isolated glenohumeral joint rotational ROM measurement is one of the most striking examples recommended in the overhead athlete. This can be performed to prevent inappropriate overstretching and potential harm to a hypermobile shoulder should ROM interventions be given out in the overhead athlete population as a whole without thoughtful measurement and evidence-based individual application of ROM interventions.

Range of Motion Interventions

A series of published studies can guide and provide evidence for the clinician in the development of intervention strategies to modify injury risk in the specific overhead athlete who presents with true dominant arm internal rotation and total rotation ROM loss (P-GIRD) and requires intervention based on objective measurement. Recent research by Izumi et al. [25] has shown that large strains were found in the posterior capsule in a stretching position of 30° of elevation in the scapular plane with IR. These researchers compared many positions of shoulder ROM to determine what position optimally placed stress on the posterior capsule. This internally rotated position with the shoulder elevated 30° in the scapular plane produced very acceptable levels of posterior capsular strain and would be very effective for clinical use. These stretches for the posterior capsule and muscle tendon unit (posterior shoulder stretches) can be used in a proprioceptive neuromuscular facilitation (PNF) contract-relax format or following a low-load prolonged stretch-type paradigm to facilitate the increase in ROM [26, 27]. Figures 10.3 and 10.4 show versions of clinical IR

Fig. 10.3 “Figure 4” internal rotation stretching technique

Fig. 10.4 Stabilized internal rotation stretching technique in the scapular plane with posterior humeral head stabilization

Fig. 10.5 Traditional side-lying sleeper stretch

Fig. 10.6 Rollback sleeper stretch

Fig. 10.7 Cross-arm adduction with clinician stabilization of the lateral border of the scapula

stretching positions that utilize the scapular plane, and that can be performed in multiple and varied positions of GH abduction. Each inherently possesses an anterior hand placement, used to give varying degrees of posterior pressure to minimize scapular compensation and also to provide a checkrein against anterior humeral head translation during the IR stretch because of the effects of obligate translation. Additionally, the traditional sleeper stretch (Fig. 10.5) and modified rollback sleeper stretch (Fig. 10.6) [22] as well as the cross-arm adduction stretch variations (Figs. 10.7, 10.8 and 10.9) are examples of stretches used in the clinic to address IR ROM deficiency under the direct guidance of the clinician. The sleeper and cross-arm stretches are also given to patients to address IR ROM deficiency with home exercise programs as well. It is important to note that both of these home stretches use inherent means of scapular stabilization, which are necessary to optimize the value of the stretching procedure.

Fig. 10.8 Cross-arm adduction stretch with mobilization belt distraction

Fig. 10.9 Cross-arm adduction with patient assisting with concomitant IR range of motion stretch

Slamh et al. [28] compared the use of cross-arm stretching with and without scapular stabilization in volleyball players. They found significantly greater increases in both horizontal adduction and internal rotation ROM in the group using cross-arm adduction stretching with scapular stabilization. This highlights the importance of scapular stabilization not only in the measurement of accurate ROM in the overhead athlete but the imperative inclusion during the application of manual therapy and self-stretching techniques to address ROM loss. The sleeper stretch uses the patient's body weight on the lateral border of the scapula, and a wall or supportive object is used during the cross-arm stretch to prevent protraction of the scapula during the cross-arm movement.

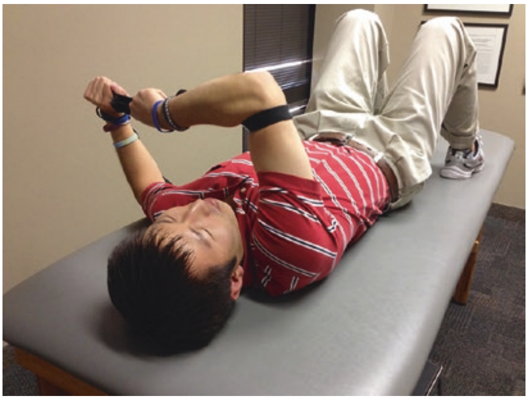

Fig. 10.10 Cross-arm contract-relax stretch using stretch strap to improve IR range of motion

McClure et al. [29] have compared the effects of the cross-arm stretch versus the sleeper stretch in a population of recreational athletes, some with significant GH IR ROM deficiency. Four weeks of stretching produced significantly greater IR gains in the group performing the cross-body stretch as compared with the sleeper stretch. Further research is clearly needed to better define the optimal application of these stretches; however, studies have shown improvement in IR ROM with a home stretching program [29]. Additionally, Laudner et al. [30] had studied the sleeper stretch and found that three consecutive 30 second sleeper stretches produce 3.1° of increased internal rotation immediately after stretching in overhead athletes. Similarly, use of an independent contract-relax stretching technique using a stretch strap (Fig. 10.10) has been found to produce increases of 8.26° in internal rotation in uninjured subjects [31]. Moore et al. [32] applied a muscle energy-type (contract-relax) technique in the directions of horizontal adduction and internal rotation to improve posterior shoulder tightness. Results of their study showed significantly greater improvements in IR and horizontal adduction ROM following the MET application in the direction of horizontal adduction than both a control group and a group of subjects receiving the MET in the direction of IR. This study shows support for the single application of MET in the direction of cross-arm adduction to improve both IR and horizontal adduction ROM. The sleeper and cross-arm stretches can be recommended for patients and for overhead athletes to address internal rotation range of motion limitation in addition to the procedures recommended here for clinical use.

Manske et al. [33] studied the effect of adding a posterior glide mobilization by a physical therapist to cross-arm adduction stretches over a 4-week experimental paradigm. Results after 4 weeks of posterior shoulder stretching or posterior shoulder stretching with posterior glide mobilization showed no significant difference between groups. This finding indicates that the posterior glide mobilization did not significantly increase internal rotation range of motion over posterior shoulder stretching (cross-arm adduction stretching) alone. The use of posterior glide mobilization to increase internal rotation ROM in the overhead athlete would only be reserved for those individuals who had a significant reduction in manually assessed posterior translation using a posterior lateral assessment technique to ensure proper translation along the line of the glenohumeral joint (Fig. 10.11).

Bailey et al. [34] studied the effects of instrument-assisted soft tissue mobilization combined with static stretching in baseball pitchers with typical dominant arm range of motion loss. Their results showed instrument-assisted soft tissue mobilization combined with stretching to be superior to stretching alone. Stretching consisted of both the cross-arm and sleeper stretches, while the instrumented soft tissue mobilization consisted of 2 minutes of application to the infraspinatus and teres minor muscles.

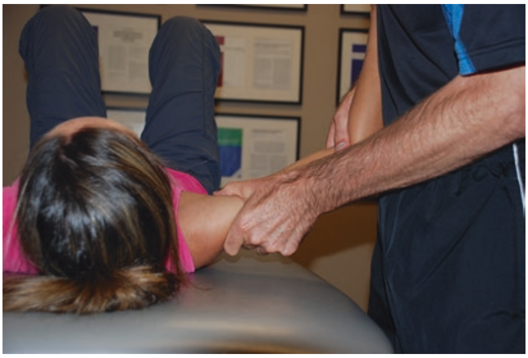

Fig. 10.11 Posterior glide examination and mobilization technique

In a similar study, Fairall et al. [35] studied the effects of self-myofascial release and static stretching using the side-lying sleeper and cross-arm stretches. The self-myofascial release technique consisted of two sets of 60 second rolling on a LaCrosse ball over the infraspinatus and teres minor muscles. Results of their study support the use of static stretching and self-mobilization plus static stretching, to improve IR ROM in overhead athletes with GIRD. Both conditions were superior with respect to ROM increases in IR ROM over self- myofascial release alone.

While a copious series of studies has been published in the experimental literature in the past decade, several deal with only the acute responses to ROM interventions. Reinold et al. [36] demonstrated the acute effects of pitching on GH ROM. Sixty-seven professional baseball pitchers were measured for GH joint rotational ROM with the use of scapular stabilization before and immediately after 50–60 pitches at full intensity. Results show a loss of 9.5° of IR and 10.7° of total rotation ROM during this short-term response to overhead throwing. This study shows significant decreases in IR and total rotation ROM of the dominant GH joint in professional pitchers following an acute episode of throwing. Reinold et al. [36] suggest that muscle tendinous adaptations from eccentric loading likely are implicated in this ROM adaptation following throwing (a term known as thixotropy). This musculotendinous adaptation may occur in addition to the osseous and capsular mechanisms previously reported [36]. Additionally, Martin et al. [37] measured shoulder IR, ER, and total rotation in elite-level male tennis players before, during, and after a 3 hour tennis match. Their study identified losses of 20° in IR and 24° of total rotation ROM in the dominant arm following the tennis match. Moore et al. [38] similarly identified pre- to post-match significant decreases in shoulder IR and total rotation ROM in 79 professional female tennis players. These decreases in shoulder IR and total rotation ROM were reported in 47% and 37% of the elite tennis players, respectively. These studies provide brilliant rationale for the inherent need of ongoing interventions to control and limit shoulder IR and total rotation ROM loss from repetitive overhead athletic movement patterns like throwing and serving. Research showing the effects of ongoing interventions to address shoulder ROM alternations and thus influence this aspect or risk factor for overhead athletes is imperative to better our understanding as researchers and clinicians who work with overhead athletes. Thus, long-term monitoring of shoulder ROM appears indicated given the repeated acute stressors inherent in throwing and serving movement patterns and their potential to create shoulder ROM alterations.

Aldridge et al. [39] reported improvement in IR and total rotation ROM following a 12-week program of sleeper stretches in NCAA division I professional baseball players. Additionally, Lintner et al. [40] report on professional baseball pitchers who had participated in a regular shoulder ROM program for over 3 or more years as compared to pitchers who had participated for less than 3 years. Their analysis identified greater dominant arm IR ROM (74° v 54°) in the group of professional baseball pitchers who had been involved in an IR stretching program demonstrating the potential benefits of a long-term program to modify injury risk from ROM in the dominant shoulder in the overhead athlete. Lastly, Kibler and Chandler [41] monitored the effects of a 2-year conditioning program in elite junior tennis players for injury risk modification. Their study identified improvements in IR ROM in junior players in the group performing shoulder ROM stretches (43° PRE/55° POST 1 year/58° POST 2 years) during the conditioning program. These studies do show long-term or chronic manipulation or modification or shoulder ROM, particularly IR ROM in the dominant shoulder of overhead athletes. Continued long-term study of ROM modification interventions coupled with additional correlation of direction-specific dominant shoulder ROM loss to pathologies in the shoulder and elbow are needed to more fully understand this specific injury risk factor.

Shoulder Muscle Strength, Endurance, and Unilateral Strength Ratios

Another important and modifiable risk factor in the overhead athlete is muscular strength. The most studied muscle group for obvious reasons in the overhead athlete is the rotator cuff which most often is measured in shoulder internal/external rotation [41–43] or supraspinatus via empty or full can strength testing [20, 24, 45]. Tyler et al. [24] measured 101 high school pitchers and identified an increased risk (RR = 4.58) of serious shoulder injury (>3 games missed) in the group with dominant arm supraspinatus weakness measured during preseason with a handheld dynamometer. Edouard et al. [46] reported increased dominant arm IR and ER isokinetic strength but lower ER/IR strength ratios in elite female handball players compared to a control group of non-overhead female athletes. Of significance however was the finding of an increased injury risk (RR = 2.57) in the group with lower ER/IR ratios on the dominant arm. This muscular imbalance was found to be a significant risk factor for shoulder injury in elite female handball players.

Byram et al. [47] tested professional baseball pitchers over a 5-year period with a handheld dynamometer to assess shoulder strength. They reported that both seated and prone ER strength measures as well as supraspinatus strength were significantly associated with throwing-related shoulder injuries requiring surgery in the subsequent season. Byram et al. [47] also found significant relationships between decreased ER/IR strength ratios on the dominant arm and significant shoulder injury in the same cohort of professional baseball pitchers. Their key study clearly identified the importance of measuring posterior rotator cuff strength and the ER/IR unilateral strength ratio as critical risk factors in shoulder injury.

Similarly Shitara et al. [48] tested 105 high school pitchers and found a significant relationship between dominant arm-prone external rotation weakness and 90° abducted IR strength and shoulder injury. Their study again showed the relationship between both shoulder and elbow injuries and shoulder rotator cuff strength deficiencies in the high school baseball pitcher.

Clarsen et al. [49] studied over 200 elite male handball players over a 30-week season. They measured preseason rotator cuff strength, scapular dyskinesis, and glenohumeral joint rotational ROM. A 28% prevalence of shoulder injuries occurred over the course of the subsequent season. The presence of scapular dyskinesis, external rotation weakness, and total rotation ROM loss all increased the risk of dominant arm shoulder injuries in this population. Like the prior studies, this study supports and highlights the need for posterior rotator cuff strengthening in addition to ROM monitoring in overhead athletes. Finally, Miller et al. [50] performed a systematic review of injuries in water polo. They found high incidences in their review of shoulder injury (24–51%) in 20 studies. Most of the 20 studies reported descriptive data and concluded that shoulder injuries in water polo are indeed multifactorial. Proposed risk factors are ROM loss, muscular strength imbalances (ratios), volume of throwing, and scapular dyskinesis.

In summary, in many sports, proposed risk factors include decreased ER and supraspinatus strength as well as ER/IR strength ratio imbalances, but in most studies these risk factors are not statistically confirmed in prospective studies. This brief review at the present time highlights the significant need for additional research comparing sport-specific risk factors and providing evidence for the role each risk factor plays in shoulder and upper extremity injury in the overhead athlete.

Measuring Shoulder Strength for Injury Risk Modification in the Overhead Athlete

The prior section highlights the need for accurate objective strength measurement to closely monitor the overhead athlete for this important risk factor. The use of both isokinetic and handheld dynamometers has been reported in the literature [19]. These studies provide descriptive profiles of specific overhead athlete populations. These descriptive profiles have identified consistently that significantly greater dominant arm internal rotation strength is present with either no significant difference in external rotation strength or actually greater non-dominant extremity external rotation strength present in the thrower and elite tennis player [1, 18–20, 42–44, 51]. These studies provide objective data profiles for torque and work relative to body weight as well as the important ER/IR ratio in normal healthy overhead athletes. It is beyond the scope of this chapter to list these descriptive profiles here, but the reader is referred to these specific studies and review articles that contain these data. These studies all test the athlete in 90° of glenohumeral joint abduction starting in 90° of glenohumeral joint abduction (Fig. 10.12). These studies can be used to apply testing data that is dynamometer specific and guide clinicians in the interpretation of results from these important tests. Data from other studies using handheld dynamometers with throwing athletes [18–20, 45] can guide the clinician in interpretation of that data. Ellenbecker [18, 19] has shown differences in the relationship between bilateral ER strength in elite junior and professional tennis players based on the position of testing. For testing ER with the arm at the side (Fig. 10.13), elite level tennis players are weaker on their dominant arm by 1–2 KG compared to their non-dominant extremity. Additionally, when testing ER at 90° of abduction, (Fig. 10.14) equal strength in ER is encountered bilaterally. This difference highlights the importance of testing the overhead athlete in both neutral (arm at side)

Fig. 10.12 Isokinetic shoulder internal/external rotation testing position with the shoulder in 90 90 position

Fig. 10.13 Handheld dynamometer testing of ER in neutral ab/adduction for infraspinatus

Fig. 10.14 Handheld dynamometer testing of ER in 90° of coronal plane abduction for teres minor

ab-/adduction and in 90° of abduction as well [18–20]. Several studies [47, 48] also use the prone position and have reported reliable data in this position with 90° of glenohumeral joint abduction. Kurokawa et al. [52] have expertly shown in an elaborate study using PET scans that ER testing at the side favors the infraspinatus, while testing the shoulder in 90° of abduction favors the teres minor. This may explain the discrepancy in laterality found in elite tennis players with isometric handheld dynamometer testing in multiple positons. Ellenbecker [18–20] and others [47] have used a make test using commercially available handheld dynamometers to obtain clinically useful isometric strength data [53]. These dynamometers are more accessible and also portable to allow testing in the setting of sports medicine but lack the ability to assess the dynamic muscular function that isokinetic dynamometers inherently capture [43].

Techniques to Modify Risk Factor: Posterior Rotator Cuff Strength

While it is beyond the scope of this chapter to completely cover this important topic, it is imperative to discuss strategies and some evidence-based research that demonstrates that indeed this is a modifiable risk factor. Some of the earliest studies [54, 55] specifically with overhead athletes were performed using isokinetic dynamometers. These studies used 6 weeks of either concentric or eccentric isokinetic training performed three times per week and resulted in significant improvements in both internal and external rotation strength [54, 55] as well as improved endurance [55]. Additionally, both studies reported improvements in serve velocity alongside improvements in rotator cuff strength. Treiber et al. [56] performed a similar study using elastic resistance and light dumbbell training of the rotator cuff and also reported both shoulder internal and external rotation strength and serve velocity improvements after 4 weeks of training in collegiate tennis players.

Carter et al. [57] studied the effects of an 8-week training program of plyometric upper extremity exercise and ER strengthening with elastic resistance performed at 90° of glenohumeral joint abduction. They found increased eccentric ER strength, concentric IR strength, and improved throwing velocity in collegiate baseball players, thus showing the positive effects of plyometric and elastic resistance training in overhead athletes. These exercises have been studied by Ellenbecker et al. [58], who demonstrated high levels of peak EMG activity of the lower trapezius (118–131% MVIC) and infraspinatus (85–103%) during these important exercises. Figures 10.15 and 10.16 show plyometric exercises recommended and studied by Ellenbecker et al. for posterior rotator cuff strengthening.

DeMey et al. [59] have also shown improvements in muscular activation characteristics following a 6-week program to enhance rotator cuff and scapular strength in a training study using side-lying external rotation, prone extension, and horizontal abduction as well as side-lying shoulder flexion. These parameters improved in patients diagnosed with subacromial impingement. These exercises improve the timing of the lower trapezius and serratus anterior relative to the upper trapezius and reflect positive changes in muscle performance for patients with subacromial impingement.

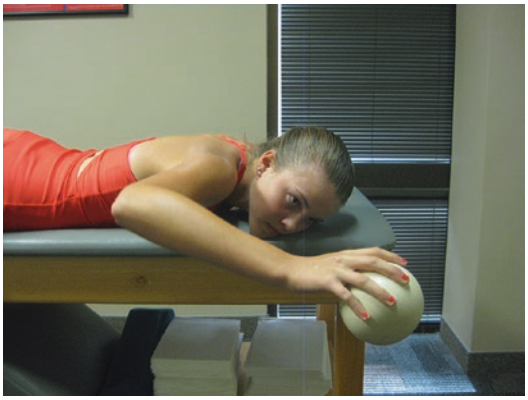

Fig. 10.15 Prone 90 90 plyometric medicine ball drops

Moncrief et al. [60] showed improvements of 8–10% in a 6-week training study using a low-resistance, high-repetition training program using a similar isotonic exercise program recommended by Cools [59] and others [21] to improve rotator cuff strength. These studies show that rotator cuff and scapular function can be modifiable using low-resistance high-repetition paradigms with isotonic weights, elastic resistance, and isokinetic and plyometric training. Lastly, Niederbracht et al. [61] utilized a 5-week training program in collegiate tennis players using only external rotation strengthening. Pre- and post-testing on an isokinetic dynamometer showed specific external rotation strength improvements from the training without concomitant internal rotation strength gains. This study addresses the important topic of normalizing or improving the ER/IR ratio which can be very imbalanced in elite-level overhead athletes [68]. Utilization of the training programs

Fig. 10.16 Reverse catch plyometric external rotation medicine ball exercise

and exercise movement patterns discussed in this section of this chapter specifically address external rotation strength deficiencies and based on the peer-reviewed work published by Niederbracht et al. [61] can provide a training stimulus to improve the ER/IR muscle balance by improving external rotation strength. The use of handheld dynamometers and isokinetic dynamometers that will allow the clinician to identify injury risk [47] and also objectively measure progress during posterior rotator cuff (external rotation)-based training programs is highly recommended. These methods coupled with the ROM components discussed earlier form two modifiable risk factors that can be monitored and changed to lower injury risk and optimize performance.

Additional Risk Factors for the Overhead Athlete

Several additional risk factors deserve specific mention in this chapter beyond the two most major factors of ROM and strength. These include scapular dysfunction and proper overhead sport biomechanics.

Scapular Dysfunction in the Overhead Athlete

Several chapters in this book are dedicated to this important topic, and the reader is referred to the first-ever textbook on this important subject for an exhaustive review of the literature and clinical application [62]. The reader is referred to the chapters in this book for important evidence-based information on the role of the scapula in the overhead athlete. Ellenbecker et al. [63] identified high levels of observable scapular dyskinesis in healthy, uninjured professional baseball pitchers and catchers in a video-based study with multiple examiners. In this study improved reliability was noted when classifying scapular dyskinesis as “yes” or “no” instead of trying to differentiate the three pathological types of scapular movement from normal scapulohumeral rhythm. Despite the finding of scapular dyskinesis in the professional baseball pitchers and catchers, there was no correlation with the number of subsequent days on the disabled list for shoulder and/or elbow injuries in the seasons following the evaluation. Further research is needed to identify the link between scapular dyskinesis and shoulder/elbow injury. Oyama et al. [64] have shown scapular movement and positional adaptations in dominant side in unilaterally dominant upper extremity sport athletes. Ellenbecker et al. [20] reported scapular dyskinesis in 52% of ATP male professional tennis players on the dominant arm and 38% on the non-dominant extremity. Ellenbecker [42] reported higher incidences of scapular dyskinesis in elite junior tennis players with 75% for the dominant arm in female players and 56 for the non-dominant, and in male elite junior players 65% dominant arm and 48% in the non-dominant arm.

Hickey et al. [65] performed a meta-analysis and systematic review and found that in 5 studies and over 400 athletes, the presence of scapular dyskinesis during baseline testing indicated a 43% increased risk of developing shoulder pain over a 9- to 24-month follow-up. Of the athletes with scapular dyskinesis in the sample, 35% had shoulder pain at follow-up; only 25% of athletes without scapular dyskinesis had shoulder pain at follow-up.

Tsuruike et al. [66] studied the relationship between the Kerlan-Jobe Orthopaedic Clinic (KJOC) Overhead Athlete Score and the presence or lack of presence of scapular dyskinesis in collegiate baseball players throughout a season. Their results showed significantly greater declines in KJOC scores in the baseball pitchers who were classified with scapular dyskinesis with no significant change pre-/postseason in the KJOC scores in the pitches without scapular dyskinesis. This study forms an initial investigation showing the effects of scapular dyskinesis on shoulder function in the overhead athlete (collegiate pitchers). Again, further research and study of the relationship between scapular dyskinesis and shoulder or elbow injury and injury risk are needed moving forward.

Sport Biomechanics

In addition to the musculoskeletal factors pertaining to injury risk in the overhead athlete, one study stands out and deserves mention. The study by Davis et al. [67] examined five specific biomechanical parameters and studied their effect on upper extremity loading in youth pitchers. These parameters included hips leading toward home plate, hand on top of ball (pronation), arm height (shoulder abduction) at stride foot contact, open/closed shoulder position during early acceleration, and stride foot position relative to home plate. The researchers found that youth pitchers who had >3 of the 5 parameters performed correctly had lower humeral internal rotation torque, lower elbow valgus load, and improved pitching efficiency as compared to the group who did not do at least 3 of the parameters correctly. Although this study does NOT directly correlate youth pitching mechanics with injury, it does show the effect of proper sport biomechanics on upper extremity loading which can create injury to the repetitive overhead athlete. Additional studies performed in other sports as well as research paradigms that correlate sport biomechanics with injury will remain very valuable and assist clinicians and sport scientists in the future.

Summary

This chapter has provided an evidence-based review of key objective parameters that can be measured and modified to affect injury risk in the overhead throwing athlete. Careful objective testing and monitoring of shoulder ROM and shoulder and scapular muscular strength and endurance are recommended based on the current evidence to decrease injury risk and enhance performance. Additional research will enhance the clinician's ability to interpret musculoskeletal screening tests to impact injury risk in the overhead athlete.

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The Role of the Scapula in the Overhead Athlete

11

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Scapular Position and Motion in Shoulder Function and Shoulder Injury

Scapular Roles

The scapula is a central link in normal shoulder and arm function during baseball activities. It is an integral part of the anatomy – the “G” of glenohumeral (G-H) and the “A” of acromioclavicular (A-C) – and is integrated with arm movement, the “S” of scapulohumeral rhythm (SHR) that produces efficient kinematics.

The scapula serves many roles in shoulder function including serving as a stable base for muscle activation, dynamically moving in relation to the arm to create precise concavity/compression ball and socket kinematics throughout arm motion, providing through its dynamic stability optimal force and energy transfer from the core to the hand, and moving to allow maximum arm abduction/external rotation. The most effective scapular position to achieve these goals is retraction, and the most effective motion is retraction and controlled protraction. Control of internal/external rotation (not allowing excessive internal rotation) and anterior/posterior tilting (not allowing anterior tilt) facilitate achievement of these goals. The loss of retraction control creates a weak link in the chain because the inability to obtain or maintain scapular retraction decreases the ability of the arm to optimally function. The loss of retraction can be caused by anatomical disruption (tissue derangement), anatomical impairment (tissue inflexibility, strength imbalance), or kinetic chain impairment (lower extremity inflexibility or weakness). These disruptions and impairments can alter scapular resting position and/or dynamic motion control and create scapular dyskinesis. Understanding how the scapula is stabilized and moves, what controls its movements, how its movements are integrated with arm movements, and the results of this integration in normal use and in shoulder injury will allow understanding of its roles in throwing and other overhead activities.

Static Position

There are wide variations in the static, resting position of the scapula. Due to the stress and frequency placed on the throwing arm, asymmetries are often present in asymptomatic players. A common asymmetry observed is an increased amount of scapular upward rotation on the

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dominant arm [1–4]. This is often thought to be a positive adaptation since increased upward rotation would theoretically increase the subacromial space and minimize the risk of subacromial impingement.

The SICK scapula (scapula infera coracoid dyskinesis) is a commonly described resting position that is thought to be suboptimal [5]. The scapula will be observed to be positioned with the inferior angle asymmetrically placed inferiorly and laterally on the thorax. It frequently represents alterations due to throwing exposure, most likely a chronic fatigue of the muscles involved with scapular upward rotation (upper trapezius, lower trapezius, and serratus anterior). Maintaining proper scapular upward rotation is important to allow optimal functioning of the glenohumeral joint and minimize the risk of developing overuse injuries such as subacromial impingement syndrome [5, 6]. It is not always associated with injury but is part of the dyskinesis-related impairment of optimal shoulder function [7].

Dynamic Motion

The overhead throwing motion is one of the fastest motions the human body can produce with velocities over 7000 degrees per second at the glenohumeral joint [8]. Due to these extreme velocities at the glenohumeral joint, the scapula also has to function at high speeds to maintain proper glenohumeral stability.

Three-Dimensional Movements

The scapula exhibits motion in three planes and translations in two directions as part of normal SHR [9–11]. The motions are upward/downward rotation around an anterior/posterior axis perpendicular to the scapula, internal/external rotation around a vertical superior to inferior axis along the medial border, and anterior/posterior tilt around a horizontal medial to lateral axis along the scapular spine [11]. The translations are elevation/depression along the thorax and protraction/retraction around the curvature of the thorax. The scapula rarely moves in only one of the motions and translations when accomplishing most scapular roles. However, loss of control of specific motions seems to alter G-H kinematics and function more than others. Loss of control of posterior tilting (allowing more anterior tilt) and loss of control of external rotation (allowing more internal rotation) appear to be most commonly associated with altered function or injury [12–15]. Normal scapular motion can be altered in asymptomatic overhead athletes due to the repetitive motions. Studies have demonstrated increased posterior tilt and upward rotation in these athletes [16, 17].

Controls for Movement

Three-dimensional scapular motion as part of SHR is initiated, controlled, and constrained by coupled muscle activations, the bony strut of the clavicle, motions due to movement of adjacent bony segments in the arm and trunk, and the motions allowed by the sternoclavicular (S-C) and A-C joints [18].

The upper and lower trapezius muscles, which usually are activated independently, and the serratus anterior muscle, contribute the most to scapular stability and mobility [19–21]. Coupling of activation of these two muscles initiates upward rotation and posterior tilt [19]. This force couple is especially active at the beginning of arm elevation [20] and with arm elevation below 90°. As the arm elevation exceeds 90°, the lower trapezius is precisely positioned to increase and maintain upward rotation through a direct line of pull [11, 20]. In this arm position, the serratus anterior works to stabilize the medial border against the thorax, acting as a scapular external rotator. As the serratus anterior stabilizes the inferior scapular angle, the lower trapezius can upwardly rotate the scapula as the arm moves [20, 22]. Lower trapezius activation is also important in the descent from maximum elevation, being activated eccentrically to control excessive anterior tilt. As the scapula rotates, torque is transmitted to the clavicle through the CC ligaments and AC ligaments to rotate the clavicle, facilitating the ability to elevate the arm [23]. Other intrinsic muscles, the rhomboids and pectoralis minor, play important but not primary roles. Extrinsic muscles, mainly the latissimus dorsi and pectoralis major, create scapular motion through their effect as prime movers of the humerus. Finally, humeral motion also can create scapular motion by tension on the G-H capsule and muscles, especially when glenohumeral internal rotation deficit (GIRD) is present.

All these muscles are activated and coordinated through the kinetic chain, in which all segments affected the activation and facilitation of the muscles. Optimal distal muscle activity for scapular stability and mobility requires the stable base of the core [24, 25].

The clavicle is the only bony attachment of the scapula and arm to the axial skeleton. The S-shaped clavicle functions as a strut to maintain scapular position, to guide and constrain scapular motions during muscle activations and arm motions, and to create a large arc of distal motion. The S-C joint allows and constrains certain clavicle motions that then allow scapular motion, and the A-C joint directly allows and constrains certain scapular motions [11]. The A-C joint is a key component of normal SHR. It acts as a pivot around which the scapula can move in efficient motions. Intact clavicular rotations and intact A-C ligaments create a reproducible screw axis of motion between the two bones and allow three-dimensional motions [26]. Both the A-C and S-C joints and the clavicle require nearly normal anatomy to be able to allow normal scapular motions.

Results for SHR and Upper Extremity Function

Several favorable results occur when SHR is optimal. The first is that optimal force transfer is allowed between the force generation site – the core – and the force delivery site, the hand [24, 27, 28]. Studies have shown that 50–55% of the kinetic energy and force delivered to the hand is generated in the core [27–30]. The large amount of muscle activity that occurs at the shoulder during overhead activity has been shown to contribute relatively little (13–20%) to the total kinetic energy or force of the entire throwing motion [28, 29] but is instead used for stability of the glenohumeral complex to allow force transfer through the shoulder to the hand [31].

At stride foot contact, as the forces are transmitted from the core to the arm, the scapula can be found to be in a retracted, slightly upwardly rotated, and anteriorly tilted position. Moving from that position to maximal external rotation, the scapula further retracts and upwardly rotates. It also moves into external rotation and posterior tilt. At maximal external rotation of the pitching motion, the scapula acts as a funnel to transfer energy from the lower extremity and trunk to the arm [6, 32]. Full scapular retraction will maximize the amount of energy transferred to the shoulder, while scapular upward rotation, external rotation, and posterior tilting will allow maximal clearance of the supraspinatus tendon. Maximum scapular internal rotation occurs after ball release and is required to dissipate the large amount of energy created during the acceleration phase.

The deceleration phase of throwing a compression force of over 1000 N occurs and can be equated to ~1.5× body weight [33]. This is more than double the forces that are experienced during the acceleration phase. This force is created by the eccentric contraction of both the posterior rotator cuff and scapular stabilizers to help dissipate energy [5, 12]. Studies have demonstrated that rotator cuff activation only dissipates 18% of the distraction load in follow-through, and trunk muscle activation dissipates 42%. The remaining 40% is dissipation by scapular muscle function to control protraction [34].

The scapula is the point of origin for all of the intrinsic and extrinsic muscles that dynamically stabilize the G-H joint in almost all ranges of motion. Muscles are responsible for G-H stability through about 90% of the motions in all planes [18]. The rotator cuff acts as a compressor cuff through force couples, helping to center the humerus on the glenoid and decreasing translations [35]. A stable base is a requirement for maximal activation of all the rotator cuff and deltoid muscles [36–39]. Demonstrated muscle strength can be improved by as much as 24% off a stabilized scapula [38, 39]. Maximal rotator cuff activation increases the compression of the humerus into the joint and can work eccentrically to dissipate energy.

Optimum scapular movements allow optimal alignment of the glenoid with the moving humerus. This most precisely creates true ball and socket kinematics, maximizing G-H rotation and minimizing G-H translation [18]. This alignment creates maximal concavity/compression by keeping the developed forces directed within the curvature of the glenoid, places minimal strain on the ligaments, places minimal compression/shearing on the labrum, allows the labrum to work maximally as a washer to distribute loads equally, and maximizes the efficiency of muscle activation by allowing them straight lines of pull [35, 40].

The combination of maximal force transfer, optimal muscle activation, and precise ball and socket kinematics allows the arm to function maximally as part of a lever system (a mechanical system that produces positive and negative work). It allows the shoulder and arm to function as both a first-class and third-class lever in the throwing athlete.

First-class levers create stability around an axis of rotation in response to a load. The shoulder is frequently required to function as a first-class lever, either when the athlete lifts weights for conditioning or when the thrower is in the cocking position of throwing, where Fleisig has calculated that the load on the shoulder is equivalent of holding a 40 pound weight in the hand [33].

Third-class levers create motion around an axis of rotation in order to move a load. Throwing the ball is a third-class lever activity. The ball is in the hand, and the prime mover muscles – pectoralis, deltoid, and latissimus dorsi – move the arm around the G-H joint fulcrum which is stabilized by scapular positioning.

The scapula is a key in both lever systems. In a first-class lever, it is the anchor point for the muscles resisting the load, and its stability creates the stable fulcrum. In a third-class lever, it is the base that allows optimum position and motion of the fulcrum. Correct usage of the lever system maximizes the efficiency of the arm for force production and force transfer.

The final result of proper scapular function is optimal position and force regulation throughout the entire arm. In an arm fatigue study, the fatigue resulted in errors of proprioception (reproducibility of arm position in the entire arm) [41]. Alterations in scapular internal/external rotation were the largest contributor to the magnitude of the error at each joint [42]. Also, scapular control is required to maximize elbow and hand force development and protect the elbow joint in throwing [28]. Although both elbow extension and wrist flexion motions contribute to hand and ball velocity at release [28], the forces that produce those motions result from interactive moments, which are forces developed by the position and motion of adjacent segments [27, 28]. The third-class lever of the shoulder, acting upon a stabilized scapula, produces a majority of these interactive moments [28]. Finally, the varus acceleration that protects against elbow valgus load is produced by the interactive moment generated through scapular and G-H internal rotation and horizontal adduction [27].

Summary

The scapula plays multiple key roles in producing normal shoulder and arm function in the overhead throwing motion. Its positions and motions are created and controlled by coordinated patterns of muscle activations and synchronized trunk and arm motions and are also controlled and constrained by the clavicle as well as the A-C and S-C joints. This creates a stable base for muscle activation, precise concavity/compression ball and socket kinematics throughout the arm motion, optimal force and energy transfer from the core to the hand, and efficient work through the lever system of the shoulder, arm, and hand. The most effective scapular position to achieve these goals is retraction. Control of internal/external rotation (not allowing excessive internal rotation) and anterior/posterior tilting (not allowing anterior tilt) facilitate the control of retraction.

Scapular Dyskinesis

Most scapular-related problems in throwing athletes can be traced to loss of control of normal resting scapular position and dynamic scapular motion. This will result in alterations in the position or motion that produce excessive protraction. This position and motion is considered an impairment, which, in the face of functional demands of the overhead motion, can create inefficiencies and deficits in the kinematics of the shoulder which can decrease performance and increase injury risk [43, 44].

Altered dynamic motion is termed scapular dyskinesis (dys, alteration of; kinesis, motion) [14]. It is characterized by medial or inferior medial scapular border prominence, early scapular elevation or shrugging upon arm elevation, and rapid downward rotation upon arm lowering [14]. The most salient clinical manifestation of protraction is asymmetric prominence of the medial scapular border. This finding has been categorized as single planar patterns of type I (inferior medial prominence), type II (entire medial border prominence), or type III (superior medial border prominence) [45]. Frequently there will be combinations of these patterns with arm motions. The dyskinetic patterns produce motions that alter the roles and results of the scapular in efficient SHR [10, 23]. Dyskinesis has been found to be present in 67–100% of patients with shoulder injuries [46, 47].

Dyskinesis results in scapular positions of increased anterior tilt, increased internal rotation, decreased upward rotation, and increased protraction. These positions have the effect of increasing the glenohumeral angle beyond the “safe zone,” of increasing anterior shear, and of increasing tensile loads on the anterior band of the inferior glenohumeral ligament [45, 48] and increasing compression loads on the posterior labrum. Excessive scapular protraction also decreases maximum rotator cuff activation, decreasing the “compressor cuff” muscle function that establishes dynamic stability. In addition, the protraction diminishes dynamic subacromial clearance of the elevating humeral head and increases potential rotator cuff impingement on the glenoid [49]. It also diminishes the ability to move into maximal abduction/external rotation (ABER), a position required for maximum performance. Finally, dyskinesis decreases the ability to dissipate the eccentric loads in follow-through.

Dyskinesis has multiple causative factors, which can be demonstrated by appropriate history, exam, imaging, and special testing. Traumatic factors include clavicle fractures, high-grade A-C joint injuries, and medial scapular muscle detachment [50–52]. Clavicle fractures may produce dyskinesis and protraction if the anatomy is not completely restored. Shortened malunions or non-unions decrease the length of the strut and alter the scapular position toward internal rotation and anterior tilt. In addition to changes in length, changes in clavicle curvature or rotation will affect scapular position or motion. Angulated fractures result in functional shortening and loss of rotation. The distal fragment in mid-shaft fractures often anteriorly rotates, due to gravity and unopposed muscle pull on the fragment, decreasing the obligatory clavicle posterior rotation and scapular posterior tilt during arm elevation [51, 53–55].

A-C joint injuries frequently result in dyskinesis. High-grade (types III–VI) A-C separations disrupt the strut function and allow a “third translation,” in which the scapula translates inferior to the clavicle and medial on the thorax, producing the dyskinesis as a clinical finding. Iatrogenic A-C joint injury due to excessive distal clavicle resection and detachment of the A-C ligaments shortens the bony strut and allows excessive scapular internal rotation due to excessive anterior/posterior motion at the A-C joint [11].

Scapular muscle detachment is a post-traumatic tearing of the rhomboids and/or lower trapezius muscles from the medial scapular border. In throwers, it occurs after a fall or as a result of repetitive high-velocity throwing. The clinical characteristics include localized point tenderness along the medial scapular border, scapular protraction, and change in symptoms after scapular corrective maneuvers [52].

Neurological factors include long thoracic nerve injury, involving serratus anterior weakness producing excessive protraction and winging of the inferior medial border [56], accessory nerve injury involving trapezius weakness producing drooping and lateral scapular tilt [57], and cervical disc disease producing C5–C6 nerve root symptoms which may radiate along the medial scapular border and may produce rhomboid weakness with decreased ability to retract the scapula. All the neurological factors are rare in the throwing population.

Intra-articular factors can produce dyskinesis by pain-derived muscle weakness, reflex-driven inhibition of coordinated muscle activation, or mechanical compensations to maintain G-H concavity-compression when the static restraints are damaged. These factors include G-H post-traumatic and multidirectional instability [46, 58–60], labral injuries [12, 61], biceps tendinopathy, and rotator cuff disease [62].

The majority of scapular dyskinesis cases have root causes related to altered soft tissue and muscle function, i.e., stiffness in flexibility, decreased strength or strength imbalance, or altered muscle activation patterns. This would be expected, since scapular motion is largely dependent upon coordinated muscle activation in force couples.

Stiffness/inflexibility may be due to muscle or joint causes. Muscle stiffness is common, probably due to large repetitive motions, high imposed eccentric forces, high frequency of overhead motions, and eccentric strength deficits [63–66]. A common finding is coracoid-based inflexibility – pectoralis minor and biceps short head. Tightness of these muscles decrease scapular posterior tilt, upward rotation, and external rotation [67]. Upper trapezius tightness produces a shrug position which can affect arm elevation. Pectoralis major and latissimus dorsi tightness can create dyskinesis through their action on the humerus.

Glenohumeral internal rotation deficit, an altered joint motion, which is related to posterior muscle stiffness and capsular tightness, creates dyskinesis by producing a “windup” of the scapula into protraction as the arm rotates into follow-through.

Decreased strength is caused most commonly by fatigue or inhibition of activation. Fatigue is defined as inability to maintain muscle force over a period of time. Fatigue that results in maladaptive patterns is commonly seen around the shoulder, in the lower trapezius [68], posterior deltoid [69], and supraspinatus [59]. It may occur in muscles that are deconditioned for the demands of the task or from exercise that is too strenuous for normally conditioned muscles. It occurs sooner in eccentric activities. Fatigue alters strength balance, joint motions, and joint loads [41, 42, 70].

Inhibition of muscle activation is the most commonly encountered reason for muscle weakness. The neuromuscular axon is intact, but there is a decrease in the activation stimulus. Inhibition may be seen in G-H joint internal derangements, such as labral injury or biceps tendinopathy, probably due to pain or capsular tension. This type of inhibition will usually resolve with treatment of the underlying problem. It may also be the result of loss of kinesthetic sense and proprioception around the scapula and G-H joint. This may be seen in athletes with chronic pain or chronic injury. It appears to be manifested in almost every type of shoulder condition, from scapular dyskinesis to G-H joint labral injury, rotator cuff injury, and arthritis. Evaluation is usually best carried out by asking the subject to voluntarily place their scapula in a retracted position without any cueing or aiding or to actively depress the abducted but stabilized arm. Those with altered kinesthetic sense are unable to accurately or powerfully accomplish the task. It is important to identify this neuromuscular maladaptation, because the inability to voluntarily activate the muscle will limit the effectiveness of otherwise appropriate exercises if the inhibition is present. Muscles such as the lower trapezius and serratus anterior appear to be more susceptible to this type of weakness, frequently being involved early in the injury and symptom process. As they are inhibited, there may be a loss of kinesthetic sense of the correct scapular position, so that attempts to stimulate the correct muscle activation for scapular retraction are difficult, leading to inefficiency in rehabilitation protocols. This is a major limitation of rehabilitation and must be identified in the evaluation. Another effect of inhibition is alteration of the muscle activation patterns that involve the affected muscles. The lower trapezius has been shown to be delayed in muscle activation during arm elevation and descent in patients with impingement symptoms [71]. Another effect of inhibition is alteration of the muscle activation patterns that involve the affected muscles. The lower trapezius has been shown to be delayed in muscle activation during arm elevation and descent in patients with impingement symptoms [71].

Muscle imbalance can affect strength and force development, disrupt the coordinated sequencing of muscle activations in the kinetic chain, alter force couple activation, alter joint motion, and change joint loading patterns. Commonly observed alterations include stronger upper trapezius coupled with weaker lower trapezius/serratus anterior, stronger subscapularis coupled with weaker infraspinatus, stronger latissimus dorsi coupled with weaker lower trapezius, stronger pectoralis minor coupled with weaker serratus anterior, and hip/core weakness, especially on the contralateral leg. This specific problem is seen in over 50% of patients with scapular dyskinesis. Mechanisms creating the imbalances include inhibition of one muscle, acute or overload injury to one muscle, and hypertrophy of one muscle due to selective training or use. The imbalances can be frequently addressed by remedial exercise programs to strengthen the muscles once the imbalance has been identified by careful strength evaluation. A specific combination of inflexibility and weakness is the lower trapezius insufficiency (LTI) pattern. Clinical findings include palpable tightness and pain in the pectoralis minor, upper trapezius, and latissimus dorsi and demonstrated weakness in the lower trapezius and serratus anterior. It is seen in 71% of patients with scapular dyskinesis.

Specific Problems in the Overhead Athlete

Scapular dyskinesis has been found in association with almost every pathologic injury in the shoulder and arm in the overhead athlete, including labral injury [12, 17], instability [46], impingement [36, 72, 73], rotator cuff disease [47], clavicle fractures [51, 54, 55, 74], A-C separations [50], and elbow injury [75]. The incidence varies, but dyskinesis can be identified in between 50% and 100% of throwers with injuries.

Labral Injury

Scapular dyskinesis has a high association with labral injury with up to 94% of injured athletes demonstrating dyskinesis [16, 61]. The altered position and motion of internal rotation and anterior tilt plus loss of upward rotation changes G-H alignment, placing increased tensile strain on the anterior ligaments [48], increases "peel-back" of the biceps/labral complex on the glenoid [12], and creates pathological internal impingement resulting in labral compression, tearing, and substance shearing [16, 76]. Only a 10° loss of upward rotation increases the area and amount of compressive impingement, while a 10° increase in internal rotation increases the amount of compressive impingement [77]. These effects are magnified in the presence of GIRD, which creates increased protraction due to "windup" of the tight posterior structures in follow-through. Evaluation for dyskinesis in patients with suspected labral injury will be a key component in developing programs for non-operative or postoperative rehabilitation. In addition, correction of the symptoms of pain found in the modified dynamic labral shear (M-DLS) test, an excellent test for detection of labral injury, can be frequently demonstrated by the scapular retraction test (SRT). This indicates the presence of dyskinesis as part of the pathophysiology and the need for scapular rehabilitation to improve scapular retraction, including mobilization of tight anterior muscles and institution of the scapular stability series of strengthening exercises.

A scapular-based rehabilitation program has been found to be successful to modify symptoms and improve performance so that surgery is not required in 41% of professional athletes [78] and 50–60% of nonprofessional but recreationally active athletes [79]. In the postoperative period following labral surgery, restoration of scapular kinematics is universally advocated as a key baseline component [61, 80, 81]. Identification of altered kinematics and their restoration are key components of injury risk modification programs.

Glenohumeral Instability

Many patients with instability demonstrate dyskinesis. The type of instability will usually determine how to address the dyskinesis. Traumatic anterior or posterior instability results in dyskinesis due to pain, muscle alteration(s), or altered joint mechanics, but dyskinesis can rarely be completely resolved in the presence of the anatomic lesion, and a scapular-based rehabilitation program is infrequently successful in resolving the dysfunction but is more commonly used to minimize recurrence during a competitive season until definitive treatment is performed [82]. However, once the anatomic lesion is stabilized, scapular rehabilitation should be one of the primary areas of focus during the early phases of postoperative treatment [83].

Symptoms in many other types of instability, especially multidirectional instability, are more related to alterations of muscle function, which then create dyskinesis. Treatment of dyskinesis has been shown to have a more central effect on symptom resolution and functional restoration [83–85].

The dyskinesis present in almost all of these patients is most commonly due to serratus anterior and lower trapezius muscles weakness. Several reports have suggested that a scapular-based rehabilitation program, focused on kinetic chain restoration, scapular stabilization in retraction, and normalization of glenohumeral rotation, can reduce symptoms and improve function so that a significant percentage of patients could return to activity [82, 86–88].

In patients with instability symptoms related to multidirectional instability, dyskinesis and altered muscle activations play a large role. Studies have demonstrated that inhibition and weakness of subscapularis, supraspinatus, serratus anterior, and lower trapezius, coupled with increased activation of pectoralis minor and latissimus dorsi, place the scapula in a protracted, downward rotated position with decreased humeral head compression [23, 59, 60, 67, 89]. The dyskinesis causes the scapula and glenoid to translate under the humeral head, creating the loss of concavity/compression and symptoms of instability in the mid-ranges of motion. Latissimus dorsi activation then becomes the destabilizing force, pulling the humeral head inferiorly over the downwardly facing glenoid. Rehabilitation programs focusing on scapular retraction, increased serratus anterior and lower trapezius strength, and flexibility of the pectoralis minor and latissimus dorsi are advocated for restoring function.

In summary, scapular dyskinesis is commonly associated with all types of G-H instability. The dyskinetic positions and motions create and exacerbate altered G-H kinematics and muscle activations by decreasing the “sea lion’s” ability to maintain “the ball” on its nose. This increases the dysfunction of the instability and can decrease the effectiveness of non-operative or postoperative rehabilitation protocols. Because dyskinesis is so prevalent in patients with instability, evaluation for the presence or absence of scapular dyskinesis should be included as part of a comprehensive examination of the unstable shoulder.

Impingement

Impingement is frequently seen in throwing athletes but is rarely a primary or isolated diagnosis. In this group, impingement may be secondary to other pathologies such as instability, labral injury, and biceps pathology or to scapular dyskinesis [90]. Scapular dyskinesis is associated with impingement by altering scapular position at rest and upon dynamic motion. Scapular dyskinesis in impingement is characterized by loss of acromial upward rotation, excessive scapular internal rotation, and excessive scapular anterior tilt [36, 73]. These positions create scapular protraction, which may decrease the subacromial space [23], increase contact on the glenoid [49], and decrease demonstrated rotator cuff strength [38, 39].

Activation sequencing patterns and strength of the muscles that stabilize the scapula are altered in patients with impingement and scapular dyskinesis. Increased upper trapezius activity, imbalance of upper trapezius/lower trapezius activation so that the lower trapezius activates later than normal, and decreased serratus anterior activation have been reported in patients with impingement

[71, 73]. Increased upper trapezius activity is clinically observed as a shrug maneuver, resulting in a type III dyskinesis pattern. This causes impingement due to lack of acromial elevation. Frequently, lower trapezius activation is weak, inhibited, or delayed, and upper trapezius, pectoralis minor, and latissimus dorsi will be tight and painful to palpation. This results in a type III/type II dyskinesis pattern, with impingement due to loss of acromial elevation and posterior tilt. Serratus anterior activation has been shown to be decreased in patients with impingement, creating a lack of scapular external rotation and elevation with arm elevation [71].

The pectoralis minor has been shown to be shortened in length in patients with impingement. This tight muscle creates a position of scapular protraction at rest and does not allow scapular posterior tilt or external rotation upon arm motion, predisposing patients to impingement symptoms [67]. In this population of throwing athletes, even in the presence of positive impingement signs and impingement tests, most cases of impingement symptoms not associated with injury can be resolved by including restoration of scapular kinematics in the rehabilitation program [91].

Rotator Cuff Injury

The rotator cuff is frequently clinically involved in throwers with shoulder symptoms, and symptoms can be exacerbated by dyskinesis. Upper trapezius spasm and tightness, pectoralis minor tightness, and lower trapezius and serratus anterior weakness are common findings. The dyskinetic protracted position that results in an internally rotated and anteriorly tilted glenoid increases the internal impingement on the posterior superior glenoid with arm external rotation and increases the torsional twisting of the rotator cuff, which may create the undersurface rotator cuff injuries seen in throwers [12, 92, 93]. In addition, scapular protraction creates superior compression loads on the rotator cuff. With continued activity, these loads result in histological and mechanical changes in the tendon that are those seen in clinical tendinopathy [62]. Finally, positions of scapular protraction have been shown to be limiting to the development of maximal rotator cuff strength.

Rehabilitation programs that address restoration of scapular mechanics have been shown to decrease rotator cuff symptoms and decrease the requests for surgery, both in partial-thickness and full-thickness tears [94]. In both non-operative and postoperative cases, early rehabilitation protocols should avoid exercises or arm positions that create protraction. These positions increase the compressive load on the tendon repair and can impair or delay optimum healing [62, 95].

Scapular testing in patients with impingement and rotator cuff injury should include the scapular assistance test (SAT) and the SRT [6, 7]. A positive SAT, reducing painful arc impingement symptoms in forward flexion, demonstrates scapular anterior tilt as part of the pathophysiology. This finding directs treatment to include increased flexibility of pectoralis minor and short head of biceps and strengthening of lower trapezius and serratus anterior as scapular external rotators and retractors. A positive SRT, increasing demonstrated rotator cuff strength, directs strengthening rehabilitation to scapular retraction, rather than rotator cuff, as the first stage of the program. Use of the retracted position to always evaluate rotator cuff strength also creates more test/retest reliability to accurately demonstrate changes in strength.

Acromioclavicular Joint Injuries

A-C joint injuries are rare in throwing athletes except football quarterbacks, but they can create major three-dimensional functional deficits due to the disruption of the important A-C linkage. The clinical problem is mainly related to alteration of scapular kinematics. Dyskinesis is found in a high percentage of patients with high-grade A-C symptoms [50]. High-grade A-C separations alter the strut function of the clavicle on the scapula and change the biomechanical screw axis of SHR, allowing excessive scapular internal rotation and protraction and decreased dynamic acromial elevation when the arm is elevated [26]. The acromion will move inferiorly, anteriorly, and medially to the clavicle, resulting in the clinical deformity. The protracted scapular position creates many of the dysfunctional problems associated with chronic A-C separations, including impingement and decreased demonstrated rotator cuff strength. However, scapular and shoulder dysfunction can also occur in type II injuries if the A-C ligaments are torn. This creates an anterior/posterior A-C joint laxity and can be associated with symptoms of pain, clicking, decreased arm elevation, and decreased shoulder function.

If dyskinesis is demonstrated on the clinical exam, this indicates the alteration of scapular kinematics that can affect shoulder function. In this case, increased attention should be directed toward correcting the biomechanical abnormality rather than just placing the arm in a sling. Treatment should include not only C-C ligament reconstruction but also A-C ligament reconstruction to completely restore the screw axis mechanism [96]. Non-operative treatment would emphasize strengthening to maximize scapular retraction stability.

Clavicle Fractures

Clavicle fractures have the capability, similar to high-grade A-C joint injuries, of disrupting scapular kinematics and SHR. In mid-shaft clavicle fractures, the weight of the arm, the pull of the biceps and pectoralis muscles, and the torque transmitted to the clavicle through the CC ligaments by the protracted scapula all create a rotational displacement force, in addition to the amount of shortening and angulation that are also present. This three-dimensional deficit yields a loss of strut efficiency for SHR and biomechanical problems including altered motion [54–56], altered glenoid orientation [97], and decreased strength [74].

Demonstration of dyskinesis on exam provides information on the alterations due to the clavicle deformity. Multiple studies conclude that operative treatment results in increased patient satisfaction, improved strength, and fewer nonunions and malunions but still have questions regarding indications for surgical treatment [98–102]. Dyskinesis could be an important piece of information to identify patients who have altered anatomy that needs correction to restore normal shoulder function.

The Scapula and the Elbow

Scapular function results in optimum position and force regulation throughout the entire arm. Dyskinesis can have several effects that can alter elbow motion, result in increased valgus load, and play a role in the etiology of elbow injuries, especially ulnar collateral ligament injuries [41, 42, 103].

Fatigue of the scapular muscles, documented by muscle weakness and demonstrated by altered scapular internal/external rotation and anterior/posterior tilt, produces compensatory motions at the elbow and inability to reproduce elbow position [41, 42, 68], both leading to increased loads.

A protracted scapula can result in altered glenohumeral angulation and potentiates the possibility of throwing out of the scapular plane, in a motion of relative humeral horizontal hyperabduction, a motion termed “slow arm” by pitching coaches. This motion increases the centripetal forces at the elbow.

Finally, dyskinesis can produce an altered arm position relative to the thorax, resulting in the “dropped elbow,” a position in which the elbow is lower than the shoulder throughout a large part of the throwing, motion, and which has been termed by pitching coaches as “the kiss of death” of the elbow. In the dropped elbow, the elbow is in flexion for a longer time (increasing valgus stress), and the amount of time the medial ligaments experience these large loads is increased.

These scapular-based impairments interact with shoulder GIRD to affect the elbow. GIRD increases scapular protraction in follow-through, thereby increasing the scapular effects. GIRD also decreases the interactive moment that produces an elbow’s varus acceleration which counteracts the applied valgus load [27, 28, 30, 40].

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Part II

Cases

12

A 12 Year Old Baseball Pitcher

Andrew Gregory

This is a 12-year-old baseball player who presents today with his mother and father who are concerned because several pitchers on his baseball team have developed shoulder problems. They want to know what they can do to prevent shoulder pain in their own son who pitches and plays third base. He has tryouts for an all-star team coming up, and they want him to be at his best. He plays baseball 4 days per week and works with a pitching coach once per week. He throws with his dad in the backyard on days off. He is in physical education class 2–3x/week and likes to play battle ball. He is right-handed. He has no previous shoulder problems; he has attention deficit hyperactivity disorder and is on Adderall.

On exam this is a slender male child in no acute distress. Examination of his right shoulder reveals no deformity, swelling, or bruising. He has full active motion. Passively he has 180° of external rotation bilaterally and 60° of internal rotation on the right compared to 90° on the left. He has 5/5 strength of the rotator cuff without pain. He has no tenderness to palpation on the proximal humerus, the coracoid, or the pectoralis minor. He has scapular dyskinesis bilaterally. He has a positive Trendelenburg test on the right and difficulty with single leg squat test bilaterally. No imaging was ordered as he had no pain.

What can my young baseball pitcher do to prevent injury? Are there any good resources? When should he specialize? – There are many good resources available from USA Baseball, the American Orthopaedic Society for Sports Medicine, and the American Academy of Pediatrics. There is no consensus on when a baseball pitcher should specialize. Most experts agree that earlier specialization can be detrimental to longevity in sport due to both injury and burnout. There is a single study that shows an increased incidence of serious injuries in professional baseball players who specialized in baseball prior to high school [1]. What is clear is that most good little league pitchers don't grow up to be big league pitchers. There is some evidence that the taller players with higher throwing velocities are most at risk for pain with throwing [2].

Should we follow pitch counts and why? What about time off between outings? Young baseball pitchers should limit their throwing volume (load) to prevent overuse injury. Most leagues now have guidelines that limit pitch count or innings for pitchers. This should include days off between pitching outings. Pitchers should not return to pitching in the same game or pitching in two games in the same day. Parents should make sure they understand their league guidelines and that they are being followed. USA Baseball has published pitch count guidelines (Table 12.1)

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Table 12.1 USA Baseball youth pitch count guidelines

Age	Daily max (pitches in game)	Required rest (pitches)					
		0 days	1 days	2 days	3 days	4 days	5 days
7–8	50	1–20	21–35	36–50	N/A	N/A	N/A
9–10	75	1–20	21–35	36–50	51–65	66+	N/A
11–12	85	1–20	21–35	36–50	51–65	66+	N/A
13–14	95	1–20	21–35	36–50	51–65	66+	N/A
15–16	95	1–30	31–45	46–60	61–75	76+	N/A
17–18	105	1–30	31–45	46–60	61–80	81+	N/A
19–22	120	1–30	31–45	46–60	61–80	81–105	106+

http://m.mlb.com/pitchsmart/pitching-guidelines/

based on age which can be used if league guidelines are not in place. For our 12-year-old patients, that limit would be a max of 85 pitches per game and a minimum of 0–4 days off depending on the number of pitches thrown.

What other positions can he play when he is not pitching? Pitchers should not be allowed to play other positions that require a lot of throwing so that they can rest their arm between pitching outings. Many leagues have rules that do not allow pitchers to catch in the same game that they have pitched in but allow them to play other infield positions that require a lot of throwing as well. First base and outfield are good positions for pitchers to get some rest from throwing when they are not pitching.

Can he play for more than one team at once? What about pitching coaches? What about other activities? Extra throwing during the baseball season should be discouraged. Playing for multiple teams in the same season, working with a pitching coach, or throwing in the backyard only adds to the throwing volume (load) which is predictive of injury. Often baseball pitchers are also throwing during other activities outside of baseball like physical education or recess. Any overhead throwing sports including football, dodgeball, battle ball, whiffle ball, and others can place additional stress on the shoulder and elbow. Underhand throwing seems to be protective for the shoulder.

What about showcases? What should we do if he has pain? High-volume activities like camps and showcases can be particularly stressful on the young shoulder and elbow. Similar pitch count limits should be maintained during these non-league activities. Any young thrower with shoulder or elbow pain should stop throwing immediately and seek medical evaluation from a medical provider preferable a pediatric sports medicine specialist. They should not return to throwing after a painful episode until cleared to do so by a medical provider. Often times this requires a period of rest followed by completion of a return to throwing program.

Are curveballs bad? What about sliders? The use of breaking pitches in the young pitchers is still controversial. Throwing a curve ball and/or slider was previously thought to cause increased elbow and shoulder pain. However it seems that throwing volume more so than pitch type is most predictive of arm pain [3]. Despite much debate about the curveball's safety in youth pitchers, limited biomechanical and most epidemiologic data do not indicate an increased risk of injury when compared with the fastball [4].

What should we focus on with his coaching? What exercises should he do? The basics of mechanics for the young pitcher are the same as that of an adult pitcher just at slower speeds [5]. Instruction should focus on form and not speed. Injury prevention exercises should be included in the instruction and training of young pitchers. Exercises should focus on scapular and core stability. It is important that young pitchers understand these exercises should be performed even if they don't have pain and may even improve their throwing performance.

How much time off should he have from baseball? Rest is important for both performance and recovery at all ages but particularly for the young athlete. A minimum of 1 day off per week is recommended. Some experts have recommend using the child's age as the limit of hours per week of a specialized sport (12 years old = maximum 12 hours per week). USA Baseball also recommends not participating in baseball activities year round. They recommend a minimum of 3 months of from throwing every 12 months. There is some evidence to support a limit of 100 innings of pitching per year [3].

In Summary recommendations for this young pitcher and his parents should include a discussion of avoiding early specialization prior to high school, age-based pitch count guidelines, playing outfield or first base when not pitching, avoiding any extra throwing during the season, and taking a minimum of 3 consecutive months off from competitive baseball per year and include strengthening exercises of the shoulder and core in the training program. Refer them to the valuable published resources from USA Baseball, the American Orthopaedic Society for Sports Medicine, and the American Academy of Pediatrics.

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A 15-Year-Old Tennis Player

13

Nicole Pitts, Jeremy Whitley, and Neeru Jayanthi

History

A 15-year-old right-hand-dominant female tennis player presents to the office for evaluation of right shoulder pain. Patient is a high-level tennis player who trains 20 hours a week and plays in about 20 tournaments per year on the international level. She only plays tennis and no other sports and has been playing since the age of 10. She has had shoulder pain for the last 2 months, and there was no inciting event. She was coming off an extensive summer season of tournament play. The pain is in the anterior shoulder, and it is worse with overhead activities most particularly with the service at the early cocking position and contact point of the serve. She denied any numbness, tingling, or weakness down her arm. She had also gone through a recent growth spurt of approximately 6 cm in the last year and has had intermittent menses. She has no prior history of shoulder injuries. She took oral NSAIDs for a few days and rested without much relief. She had no recent changes with her equipment or stroke mechanics. She utilized a dynamic warm-up before matches and practice about 50% of the time. She played in a tournament just prior to presenting to the office where she played in six matches, and then she had worse shoulder pain with lifting her arm into an overhead motion. She has had no prior imaging of this shoulder and has not done any physical therapy or rehabilitation.

Clinical Examination (Tennis-Specific Evaluation)

A full kinetic chain evaluation was performed as a normal shoulder biomechanical function requires an intact kinetic chain to create the energy, produce the forces, and stabilize the joint in tennis activities [1]. During the lower extremity assessment, her single leg balance on the stance leg was normal in stance and partial squat positions [2]. Hip abduction strength was assessed in the single-leg stance position, and she had a negative Trendelenburg sign [2]. Hip range of motion and knee extensor strength and flexibility were normal. During core and trunk

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assessment, her eccentric and concentric control of the lumbar spine was normal in the standing position as her trunk moved from hyperextension in the arm-cocking phase to a forward flexed position in the acceleration phase to trunk deceleration [2]. Her scapular examination showed positive dynamic scapular dyskinesis [3]. She had a positive impingement sign with arm elevation above 100°, with relief by the scapular assistance test [4–6]. Inspection of the shoulder showed inferior AC joint and inferior angle of the scapula on the right. Palpation exam was normal and non-tender. She had demonstrated weakness of external rotation at 0° and 90° of abduction in her dominant side. Glenohumeral internal rotation, external rotation, and total range of motion were 50°, 110°, and 160°, respectively, on the dominant side and 80°, 100°, and 180°, respectively, on the non-dominant side indicating a glenohumeral internal rotation deficit (GIRD) [7]. She had a negative active compression test [8], negative speed's test [9], and negative Roos test [10] for thoracic outlet syndrome. She had a negative anterior apprehension test [11], negative sulcus sign [12], negative lift off test [13], and negative hornblower's sign [14]. Neurological examination was normal with no deficits noted.

Imaging

X-Ray

Anterior-posterior radiographs obtained in both internal and external rotation with an axillary view were obtained. Widening of the proximal humeral physis is the hallmark of Little League shoulder. However, there may also be fragmentation of the lateral metaphysis, sclerosis, cystic changes, and demineralization of the proximal humeral metaphysis. Importantly, widening of the physis does not necessarily correlate to the severity of symptoms. An important pearl is to always obtain comparison radiographs of the non-throwing shoulder, which was also obtained and showed no difference in the physes [15]. Evaluating the subacromial space, the type of acromion, and/or presence of downsloping and visualizing calcifications (less likely in the adolescent athlete) help round out a complete plain film radiological assessment of the shoulder. Additionally, findings in the glenohumeral joint, particularly on an axillary view (i.e., calcifications), may be useful in evaluating the cause of posterior impingement. No other abnormalities were noted on X-rays.

Ultrasound of the Shoulder

A dynamic ultrasound was performed to look at acromiohumeral distance which was normal and symmetric. Ultrasound measurements of acromiohumeral distance (AHD) and tendon thickness have excellent reliability. Leong et al. [16] established cutoff distances in collegiate volleyball players and highlighted the role of ultrasound measurements for the early identification of shoulder impingement symptoms. Their approach can reasonably be applied to the adolescent tennis athlete as well.

Comprehensive Diagnosis

Differential diagnosis included rotator cuff (subacromial) impingement, tendonosis, subacromial bursitis, posterior impingement, SLAP tear, humeral epiphysiolysis, and thoracic outlet syndrome; however, these were less likely given the history and clinical examination findings.

The diagnosis in this tennis player is subacromial impingement syndrome. There are generally two types of subacromial impingement—structural and functional. While structural impingement is caused by a physical loss of area in the subacromial space (due either to bony growth or inflammation), functional impingement is a relative loss of subacromial space secondary to altered scapulohumeral mechanics resulting from glenohumeral instability and muscle imbalance [17]. This patient had a functional impingement as she had a positive scapular dyskinesis which shows altered scapulohumeral mechanics, and she has muscle imbalance by demonstrating weakness of external rotation when compared to the non-dominant side on exam. GIRD will cause scapular windup in follow-through due to posterior capsule and muscle tightness, creating protraction and increasing the dynamic impingement. This most likely led to her subacromial impingement syndrome. Other factors for her diagnosis include pain with repetitive overhead motion, pain in the cocking phase of the serve (Fig. 13.1), and positive impingement sign that improved with scapular assistance test. Although strength usually remains normal in the shoulder with impingement syndrome, this finding may be different in tennis players as they can have shoulder imbalances at baseline including (GIRD) scapular dyskinesis and dominant side weakness in external rotation [18].

Tennis-Specific Treatment Considerations

Rehabilitation

Recommendations for rehabilitation should be more functional and specific to the tennis player's injury. There are three phases in rehabilitation, acute, recovery, and functional [18]. Rehabilitation should be performed in pain-free planes during the acute phase, and the player may be removed from the sport or modifications made to temporarily hitting without certain strokes [18]. In this case the player was removed from tennis for 2 weeks. At 2 weeks her pain had improved, and she was able to lift her arm overhead with minimal pain. At this point the recovery phase was started which consists of more advanced rehabilitation such as scapular stabilization, kinetic chain strengthening, and core stabilization [18]. On her clinical exam, overall her core stabilization and kinetic chain strength was good, so the focus of recovery was placed on scapular stabilization rehabilitation for 4 weeks. Tennis-specific eccentric strengthening incorporating the kinetic chain is part of the functional rehabilitation phase [18]. She became pain-free in rehabilitation in all functional planes. She then began on court progression of upper extremity injuries, and an example of this can be seen in Fig. 13.2. She arranged an on-court evaluation to look for any biomechanical deficits that could be additional causative factors for injury.

She was also placed into an injury prevention program as it is recommended to do preconditioning prior to practice and tournament play which should include a dynamic warm-up and some functional strengthening, followed by selective post exercise stretching where indicated [18]. This included adding in stretching of the posterior capsule on the dominant side (not in external rotation) as many young tennis players are generally hypermobile with increased laxity in the shoulder with some posterior capsular tightness and GIRD.

Fig. 13.1 Associations of different phases of the serve and potential conditions involved

Early cocking: Subacromial impingement, thoracic outlet
Late cocking: Posterior (internal impingement), instability, thoracic outlet
Acceleration: Subacromial impingement, SLAP/labral tear, biceps tendinopathy
Contact point: Subacromial impingement
Follow through: SLAP/labral tear, A-C joint

Fig. 13.2 Examples of functional progression rehabilitation program

Functional Progression in the Rehabilitation of Upper Extremity Injuries

1. Throwing tennis ball from baseline line to the other side.
2. Mini-tennis from service line with swing from point of contact to follow through.
3. Mini-tennis from two-thirds court with progressively more backswing and gentle spin.
4. Full court with leg drive but no heavy spins or heavy pace.
5. Serves from baseline.
6. Full groundstrokes --•full serves --•competition.

Tennis-Specific on Court Modifications

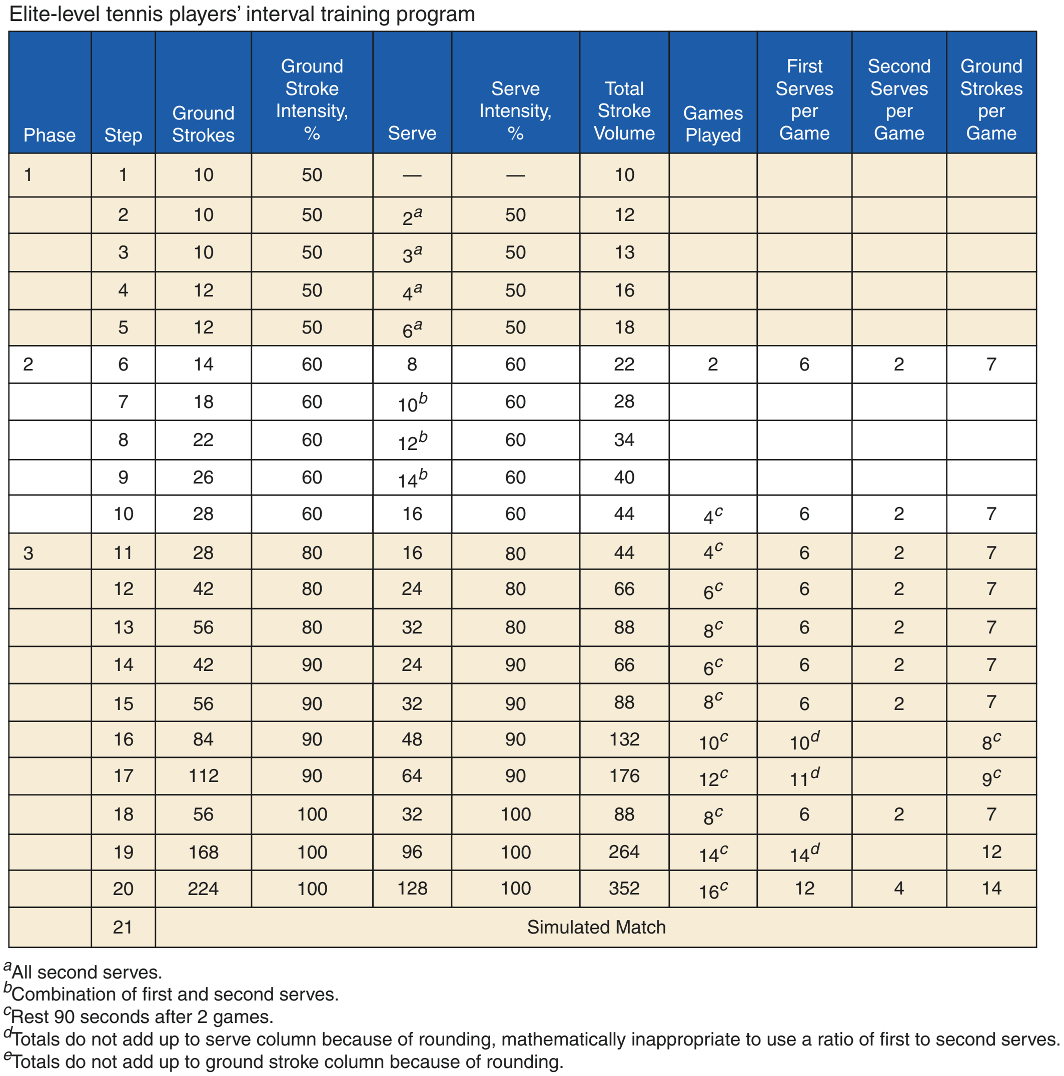
This patient was taken onto the tennis court for an on court stroke evaluation focusing mainly on her serve. This was done as utilizing diagnosis-specific stroke modifications along with on court stroke evaluations may potentially play a role in a healthy return to competitive tennis. The efficacy of this was demonstrated in a study by Jayanthi et al. [19] and showed 53 elite tennis players that were able to successfully return to competitive tennis for at least 6 months following on court evaluations and stroke modifications. In the overhead athlete, one of the biggest stressors on the shoulder can be from the serve. When the legs and trunk are not utilized to their fullest capacity during a serve, stress may be placed on the other smaller muscles in the kinetic chain, most likely the shoulder, resulting in potential shoulder injuries [19]. A valid and reliable tool assessed by Meyers et al. [20] is the observational tennis analysis (OTSA) which assesses key body positions and motions further described as “nodes” throughout the kinetic chain optimizing ball speed and efficient force production while mitigating joint loading to protect against injury. This study also found that physical characteristics of trunk mobility and power appear to discriminate serve mechanics between players. Another study by Jayanthi et al. [21] designed a stroke efficiency rating (SER) which is based off of a scoring points system and broken down into serve, forehand, and backhand. In this case we will focus on the serve. SER of the serve includes three basic components of each stroke (preparation, acceleration, and deceleration) primarily based on Kovacs et al. [22] eight-stage model of the serve.

During her serve analysis, improvements were made utilizing force generation through the pelvis prior to that of the upper extremity during the serve as that helps to decrease stress on the smaller muscles in the kinetic chain and reduce shoulder injuries [19, 23]. Some other modifications that were made to her serve included limiting lumbar extension to less than 20° in the preparation and acceleration phases and avoiding hyperangulation by reducing external rotation to less than 90° in the loading phase with limited extension of the shoulder [19]. We also had her practice retraction of the scapula in the loading/cocking phase which can be particularly helpful in rotator cuff impingement [19].

Following this she followed an interval serve progression program devised by Meyers et al. [24] to prepare tennis players to return to full match function. The program is divided into three phases (Fig. 13.3), and program progression guidelines were adopted from Axe et al. [25] (Figs. 13.4 and 13.5). During the course of her rehabilitation, she was removed from tennis for a full 2 weeks, and once she finished the serve progression program as above, she was able to get back to full match play at a high level by 3 months after the initial presentation to the office. Further recommendations were made to only play one tournament in the first month, and then she progressed to 1–2 tournaments per month with no more than 3 tournaments per month in the “heavy tournament months.”

Summary

Shoulder injuries are one of the most common injuries in junior competitive tennis players. Overuse injuries account for approximately 50% of injuries in young athletes and can be defined as those injuries that “occur due to repetitive submaximal loading of the musculoskeletal system when rest is not adequate to allow for structural adaptation to take place” [26]. The risk of development of overuse injury in a competitive junior tennis player may be dependent on intrinsic factors (such as age, gender, rehabilitative deficits) and extrinsic factors (training load and stroke mechanics) (Fig. 13.6). The key components of history are those that would help not only identify the pathology of the condition but also stratify the risk of the tennis player to low, moderate, or high risk. This may be further emphasized in return to play protocols which optimize rehabilitation of deficits, structured on court progressions, and on court stroke modifications as discussed above.

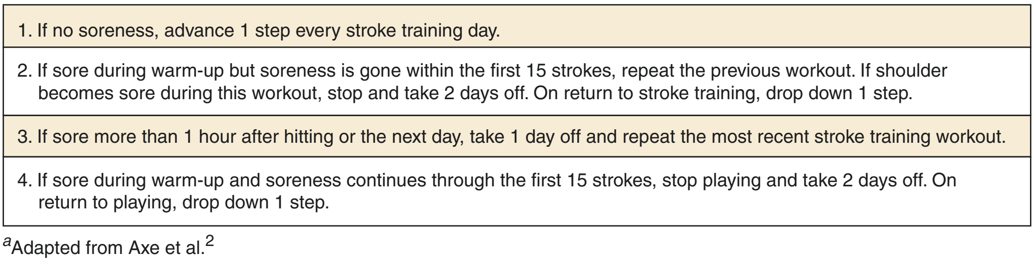


Elite-level tennis players' interval training program

Phase	Step	Ground Strokes	Ground Stroke Intensity, %	Serve	Serve Intensity, %	Total Stroke Volume	Games Played	First Serves per Game	Second Serves per Game	Ground Strokes per Game
1	1	10	50	—	—	10				
	2	10	50	2[a]	50	12				
	3	10	50	3[a]	50	13				
	4	12	50	4[a]	50	16				
	5	12	50	6[a]	50	18				
2	6	14	60	8	60	22	2	6	2	7
	7	18	60	10[b]	60	28				
	8	22	60	12[b]	60	34				
	9	26	60	14[b]	60	40				
	10	28	60	16	60	44	4[c]	6	2	7
3	11	28	80	16	80	44	4[c]	6	2	7
	12	42	80	24	80	66	6[c]	6	2	7
	13	56	80	32	80	88	8[c]	6	2	7
	14	42	90	24	90	66	6[c]	6	2	7
	15	56	90	32	90	88	8[c]	6	2	7
	16	84	90	48	90	132	10[c]	10[d]		8[c]
	17	112	90	64	90	176	12[c]	11[d]		9[c]
	18	56	100	32	100	88	8[c]	6	2	7
	19	168	100	96	100	264	14[c]	14[d]		12
	20	224	100	128	100	352	16[c]	12	4	14
	21	Simulated Match								

[a] All second serves.
[b] Combination of first and second serves.
[c] Rest 90 seconds after 2 games.
[d] Totals do not add up to serve column because of rounding, mathematically inappropriate to use a ratio of first to second serves.
[e] Totals do not add up to ground stroke column because of rounding.

Fig. 13.3 Three-phase 21-step progression to play program



1. If no soreness, advance 1 step every stroke training day.
2. If sore during warm-up but soreness is gone within the first 15 strokes, repeat the previous workout. If shoulder becomes sore during this workout, stop and take 2 days off. On return to stroke training, drop down 1 step.
3. If sore more than 1 hour after hitting or the next day, take 1 day off and repeat the most recent stroke training workout.
4. If sore during warm-up and soreness continues through the first 15 strokes, stop playing and take 2 days off. On return to playing, drop down 1 step.

[a] Adapted from Axe et al.[2]

Fig. 13.4 Program progression guidelines. (Adapted from Axe et al. [25])

Nonserving arm injury	After medical clearance, begin with step 1 and advance 1 step daily, following soreness rules and performance capability
Serving arm injury: bruise or bone involvement	After medical clearance, begin with step 1 and advance every other day, following soreness rules and performance capability
Serving arm injury: tendon/ligament (mild)	After medical clearance, begin with step 1 and advance program to step 6 every other day, following soreness rules; advance program as soreness rules allow until the end of the program
Serving arm injury: tendon/ligament (moderate, severe)	After medical clearance, begin with step 1. For steps 1-6, advance no more than 1 step every 3 days, with a day of active rest[b] after each workout day. For steps 7-18, advance no more than 1 step every 3 days, with 2 days of active rest after each workout day. Advance program following soreness rules and performance capability

[a]Adapted from Axe et al.[2]

[b]Active rest may include cardiovascular activity and short-game work from the service line to the net. Avoid overhead activity.

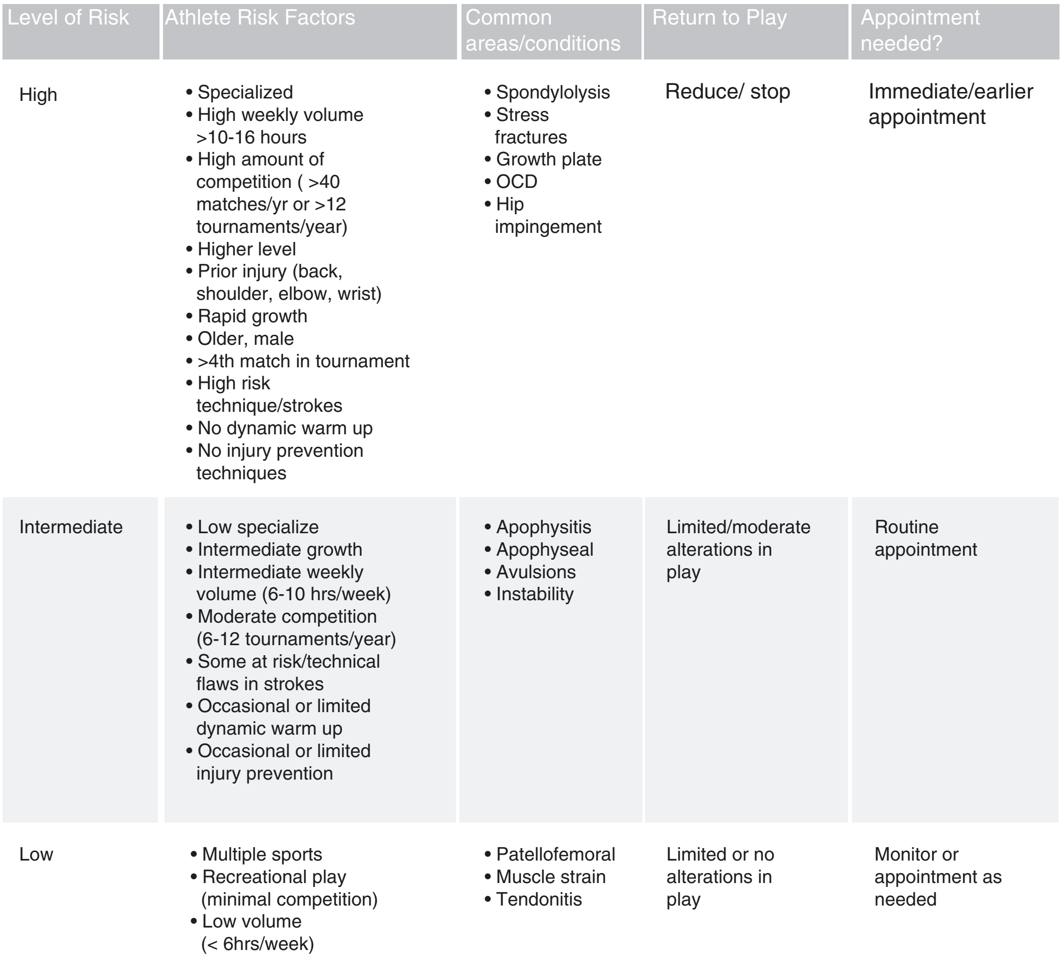
Fig. 13.5 Program progression guidelines by injury classification. (Adapted from Axe et al. [25])

Fig. 13.6 Risk factors for junior/elite tennis players

Age: Increased risk with increased age
Growth Rate: Potentially increased risk of injury during rapid growth phases.
Exposure: Increased risk with age>hours and >16 hours/week training
Competition: Increased risk of injury with competition versus practice
Prior injury: Increased risk with prior injury
Degree of sports specialization: Overuse injury is increased with higher degree of sports specialization
Gender: Female Young Athletes are more at risk for overuse injuries
Sports Training Ratio: Increased risk of overuse injury with increased ratio (2:1) weekly hours of organized sports: weekly hours of free play
Stroke mechanics: Recent stroke changes or inefficient stroke production may lead to overuse injury

In general, shoulder injuries may also be reduced by reducing volume of competition and training. Injury risk increases with volume in tournament play especially from their fifth match and beyond most notably in older age divisions [27]. Between matches it is recommended to have at least 1-hour minimum of rest especially if the most recent match was played in the heat [27]. During rapid growth, stages should exercise caution with intense training and competition [27]. To reduce injury risk, you could consider reducing tournaments to less than 2 per month, under 18 in the calendar year, training less than 16 hours per week, and taking off more than 1 day per week [27]. Jayanthi et al. [28] have demonstrated that there is a 1.5 times increase in risk of injury (typically overuse) in junior tennis players whom specialize only in tennis. However, there is emerging evidence that “undertraining” may also put an athlete at risk. Gabbet et al. [29] suggested maintaining a chronic workload ratio between 0.8 and 1.5 (acute workload (hrs/week)/chronic workload (avg hrs/week/4 weeks). An individualized approach is needed to be taken in return to play decisions. Return to play can range from being fully restricted from the sport until fully evaluated, and treatment is complete to a modified return to play or continuing to play during treatment of injury depending on the risk level of the athlete and injury (Fig. 13.7).

In this case the patient had numerous risk factors for injury. She is considered having a high-risk level of injury given the following: specialized to only play tennis, high weekly volume > 10–16 hours, high amount of competition (greater than 12 tournaments/year), higher-level tennis player, rapid growth recently, she had just played greater than her fourth match in a tournament, and did not always follow a dynamic warm-up or use many injury prevention techniques (Fig. 13.7). Given this information and her pain with overhead motion on her initial presentation to the office, the decision was made to remove her from tennis before progressing



Level of Risk	Athlete Risk Factors	Common areas/conditions	Return to Play	Appointment needed?
High	• Specialized • High weekly volume >10-16 hours • High amount of competition (>40 matches/yr or >12 tournaments/year) • Higher level • Prior injury (back, shoulder, elbow, wrist) • Rapid growth • Older, male • >4th match in tournament • High risk technique/strokes • No dynamic warm up • No injury prevention techniques	• Spondylolysis • Stress fractures • Growth plate • OCD • Hip impingement	Reduce/ stop	Immediate/earlier appointment
Intermediate	• Low specialize • Intermediate growth • Intermediate weekly volume (6-10 hrs/week) • Moderate competition (6-12 tournaments/year) • Some at risk/technical flaws in strokes • Occasional or limited dynamic warm up • Occasional or limited injury prevention	• Apophysitis • Apophyseal • Avulsions • Instability	Limited/moderate alterations in play	Routine appointment
Low	• Multiple sports • Recreational play (minimal competition) • Low volume (< 6hrs/week)	• Patellofemoral • Muscle strain • Tendonitis	Limited or no alterations in play	Monitor or appointment as needed

Fig. 13.7 Junior competitive tennis player, risk factor table

through further rehabilitation and on court return to play program. By following a tennis-specific rehabilitation program, having an on court analysis and modifying her serve technique along with incorporating an injury prevention program, the patient was able to return to full play at a high level.

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14

A 16-Year-Old Softball Pitcher with a Sore Shoulder

Jason L. Zaremski

Introduction

A 16-year-old windmill softball pitcher presented with right (dominant) shoulder pain. The pain was anterior and associated with pitching. The pain has been intermittent since she was 14 years old and typically resolves after a few weeks of rest and with over-the-counter anti-inflammatory medication. She states she does not want to miss any time from her travel team because there is an important tournament where there will be collegiate scouts in 2 weeks. Her pain is described as aching but worsens with increased volume of pitches thrown each game. She denies any pain in her neck, elbow, forearm, wrist, or hand. Her parents mention that in addition to her varsity high school team, their daughter participates in a travel softball team each summer as well as showcases on weekends in the fall months as it is her goal to pitch collegiately. She has played softball exclusively since she entered high school more than 2 years ago. When questioned further regarding the volume of pitches she pitches in a game and the number of games she pitches in per week and month, she states “I don’t know, only baseball players have pitch counts, don’t they?” She does mention she takes November and December off from pitching before returning to her high school team in January.

Examination and the Kinetic Chain

The examination reveals tenderness to the proximal long head of the bicep tendon. She performed five one-legged squats with good balance. Her external ROM in her dominant shoulder was 120° compared to 110° in her non-dominant shoulder; her internal ROM in her dominant shoulder was 45° versus 55° in her non-dominant shoulder, demonstrating equal total arc of motion. Shoulder examination maneuvers revealed pain with a biceps load test as well as irritation with a speed’s test and O’Brien’s maneuver. Crank test, dynamic modified labral shear test, Sulcus sign, and load and shift testing did not produce pain or feelings of instability. Rotator cuff strength was normal to resistance testing. The neurovascular examination was normal for light touch sensation and reflexes that were symmetric to both upper extremities. There was no appreciation of scapular winging, asymmetric scapular tilting at rest, or lack or upward rotation with active scapular range of motion and dynamic examination. The cervical spine examination was normal as there

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was no tenderness to palpation with full active ROM in all directions. Spurling maneuver did not reproduce radicular symptoms bilaterally.

Differential Diagnosis and Next Steps

Based upon the history and clinical examination, radiographs of the right shoulder were ordered to rule out bony abnormalities of the scapula-thoracic complex as well as the glenohumeral and acromioclavicular joints. The radiographs are normal. Differential diagnosis includes long head of biceps tendon pathology (tendonitis, tendinopathy, or a partial tear) as well as potential glenoid labral injury. Given our patient is a throwing athlete, we recommend a magnetic resonance imaging examination with an arthrogram (MRA) to assess for any potential long head of biceps tendon pathology and or labral injury before initiating therapeutic interventions to have a more accurate diagnosis of the soft tissue injury. The explanation for obtaining a MRA prior to initiating physical therapy was due to the concern for a possible biceps-labral complex injury. Given the patient evaluation was at the start of her season, we wanted to confirm the diagnosis to minimize possible missed time from sport as well as tailor her physical therapy regimen. It should be emphasized, however, that current literature indicates that about 50% of individuals with labral pathology can return to sports with a rehabilitation program [1, 2]. The sensitivity, specificity, and accuracy for MRA for detecting superior labral anterior to posterior (SLAP) injuries have been reported to be 82–100%, 71–98%, and 83–94%, respectively [3–6]. However, a combination of physical examination maneuvers may be more accurate to rule in a SLAP lesion than a MRA [7, 8]. Musculoskeletal ultrasonography can also be an advanced imaging modality used to assess for extra-articular long head biceps tendon pathology, but MRI can be helpful if intra-articular pathology of the shoulder is suspected as well. The MRA in our patient reveals there is fluid about the proximal long head in the biceps tendon within its sheath and fraying of the superior glenoid labrum without any signs of a discrete tear.

Next Steps: Initial Restrictions

Our patient has clinical symptoms and imaging signs of proximal long head biceps tendonitis as well as fraying of her superior labrum. Combined with the historical data provided, it is very likely this 16-year-old softball pitcher has an acute on chronic injury due to overuse. Hence, the first step is to restrict throwing. Our recommendations include restriction from throwing after the clinical examination and medical encounter. Shanley et al. revealed that injured softball pitchers threw an average of nearly 20 more pitches per game than non-injured pitchers at the high school level [9]. Throwing volume has been identified as a potential source of overuse arm injury [9–12]. Resources have been developed to guide coaches and parents regarding pitch counts and activity exposures for baseball, but these same resources do not exist for softball. Currently, there are no published pitch restrictions in softball at any level, though there are innings restrictions and recommended rest day recommendations through Little League Softball based on age level [13, 14]. With respect to batting, as long as there is no pain in the affected joint, there are no restrictions to hitting. Allowance for participation in playing a position with less cumulative and intense stress on the throwing arm (such as first base or second base) as long as submaximal overhead throwing does not exacerbate symptoms may be considered as well.

Next Steps: Rehabilitation

Once diagnosis is made and restriction from throwing initiated, the next step in treatment is to begin a non-throwing rehabilitation program. A typical rehabilitative program is a four-stage process. The four stages (acute, intermediate, advanced strengthening, and return to activity) [15] do not have a set time period, particularly in

Table 14.1 Goals in a rehabilitative program for throwing athletes [15]

Phase	Primary goals
I: Acute	Reduce pain and inflammation Restore range of motion Reestablish muscular balance and delay muscular atrophy
II: Intermediate	Progress strengthening program Reestablish muscular balance and enhance dynamic stability Improve flexibility
III: Advanced strengthening	Advance neuromuscular control Improve strength, power, and endurance
IV: Return to activity	Initiate return to throw program Return to competition Maintain strength and flexibility drills

Adapted from Wilk et al. 2016 [15]

a nonoperative rehabilitation program but have the same goal in order for the athlete to progress to each subsequent stage: there should not be pain or significant soreness after completion of each stage. Table 14.1 refers to the goals for each stage. The principles of any rehabilitative program for throwing athletes include but are not limited to diminished pain and inflammation, restoration for shoulder ROM, improved neuromuscular control, strengthening and dynamic stabilization of the rotator cuff, strengthening the flexor forearm musculature and trunk/core/pelvic muscles, scapular stabilization, and improvement in strength, power, and endurance through a return to pitch program [15–17]. Rhythmic stabilization should also be incorporated to improve dynamic stabilization [16]. Given our patient had some fraying of her labrum at the biceps insertion, care to avoid placing the patient's shoulder in positions that create stress to the biceps anchor [18], such as placing a heavy eccentric load as well as excessive external rotation at eye level on the patient until she is asymptomatic is suggested due to the forces that could be imbued on the shoulder-labral complex [18, 19].

One patient-reported outcome measurement that may be used to predict a potential risk to a throwing injury as well as assess a throwing athlete's responsiveness to treatment and rehabilitation is the Kerlan-Jobe Orthopaedic Clinic Questionnaire (KJOC-Q). The KJOC-Q has been validated as sensitive measure for upper extremity dysfunction in throwing athletes and swimmers [20–23]. Recent data by Holtz and O'Connor have provided data using the KJOC-Q in youth softball players and revealed that preseason KJOC scores of less than 90 place pitchers at an increased for developing a throwing injury during the season [20].

Throwing Program

Part of a rehabilitation process for any throwing athlete involves participation in a return to throw or pitch program once the athlete is asymptomatic and has participated in a non-throwing rehabilitation program first [24–28]. One such program is listed in Table 14.2. While there are various exertional scales of physical activity (such as the Borg rating of perceived exertion) [29], it is challenging to explain to a teenage athlete the difference between various levels of effort (such as 50% versus 75%) when pitching. Our recommendations have typically been to instruct the throwing athlete to visualize pitching at 100% and then reduce

Table 14.2 Sample return to windmill pitch program

Phases	Distance	% effort	# of pitches (× sets)
Phase 1	20 feet	50%	10 × 2
Phase 2	35 feet	50%	10 × 2
Phase 3	46 feet	50%	10 × 2
Phase 4	46 feet	50%	10 × 3
Phase 5	46 feet	50%	15 × 3
Phase 6	46 feet	50%	15 × 4
Phase 7	46 feet	75%	10 × 3
Phase 8	46 feet	75%	15 × 3
Phase 9	46 feet	75%	15 × 4
Phase 10	46 feet	100%	10 × 3
Phase 11	46 feet	100%	15 × 3
Phase 12	46 feet	100%	Preinjury pitching repertoire (15 × 4)

Warm up for 5–10 minutes (upper body and lower body) first
All pitches should be fastballs (no off speed pitches until phase 8)
Each phase is 1 week unless directed by your (PT/ATC/or physician)
There should be an off day after each pitching day
Rest 2–5 minutes between sets when pitching

his/her effort and intensity subjectively. It should also be stated that the return to pitch program should be gradually progressive so that the athlete advances only if there is no soreness or pain with throwing or after throwing each day [26]. The patient completed a return to pitch program without any pain or limited ROM during her pitching sessions or the next day.

Epidemiology of Softball Shoulder Injuries

The shoulder is the most common location of shoulder injury in softball players with the overall injury rate in high school softball players reported to be at 1.00 injury per 10,000 athlete exposures (AEs) compared to 1.72 injuries per 10,000 AEs in baseball [30, 31]. More than 27% of shoulder injuries in softball resulted in more than 10 days of lost competition [32], and more than 5% of softball athletes sustained an injury that required surgery, with a greater likelihood of surgery if the player is a pitcher [30]. Injuries sustained by pitchers were nearly three times greater than in position players and are most likely to occur in the first 4 to 6 weeks of the season [33, 34].

Differences in Windmill Versus Overhead Pitching

Windmill softball pitchers' pitching cycle is different from the baseball pitcher. There are four main phases: the windup, stride, delivery, and follow-through. Table 14.3 breaks down the phases in more thorough detail, and Fig. 14.1a–f provides visualization of each phase [31, 35]. A unique aspect to windmill pitching is more than 480° of shoulder rotation due to the clockwise and counterclockwise motion needed to generate the speed and force to pitch in this manner [35]. There are also velocity and kinetic differences in the shoulder of the windmill pitcher versus the baseball pitcher. Shoulder internal rotation torque during shoulder flexion and adduction, shoulder anterior force with pelvis and upper torso rotation, and shoulder posterior force during deceleration in a windmill softball pitcher are all similar or greater than overhead pitching [35]. These forces place high eccentric loads on the posterior shoulder musculature [35]. Furthermore, the increased shoulder anterior force creates an increased load on the biceps-labrum complex. This results in an increased necessity to resist glenohumeral distraction, which in turn can result in overuse injuries to the biceps and or labrum, similar to our patient [35].

Table 14.3 Windmill pitching phases. Adapted from Lear and Barrentine [31, 35]

Phase	Description	Increased muscle activation
Windup	Initial movement to striding leg toe off	Lowest magnitude of kinetic and kinematic forces
Early stride	6 to 3 o'clock position	SS, IS, TM, and deltoid Contralateral gluteal muscles
Acceleration	3 to 12 o'clock position	IS, TM, and deltoid
Late stride part 1	12 to 9 o'clock position	Increased humeral rotation PM, Subs, SA, and BB
Late stride part 2	9 o'clock position to release	Increased humeral rotation PM, Subs, SA, and BB
Follow-through	Ball release to end of motion in throwing arm	TM

SS supraspinatus, *IS* infraspinatus, *TM* teres minor, *PM* pectoralis major, *SubS* subscapularis, *SA* serratus anterior, *BB* biceps brachii

Injury Risk Modification

Ultimately, injury risk may be mitigated through a four-pronged approach:

- Fatigue thresholds
- Kinetic chain training program
- Pitch volume monitoring
- Throwing/pitching mechanics evaluation (Fig. 14.2a–c)

Increased volume of pitching in windmill pitchers has been shown to lead to muscular fatigue and pain during the course of a game and season. Specifically, weakness develops in the hips, trapezius, rhomboids, forearm flexors, rotator cuff, and biceps in windmill pitchers [36–39]. Concentrating on these specific muscle groups in training may lead to increased muscular fatigue thresholds in windmill pitchers. A kinetic chain program that incorporates muscular activation

Fig. 14.1 (**a-f**) Windmill pitch phases

Fig. 14.1 (continued)

and strengthening of the pelvis, torso, and gluteal musculature has been shown to be beneficial in softball catchers through more efficient transference of energy from the legs to the arms [40]. These can be included in the off-season kinetic chain training program. Studies have demonstrated that these programs can improve strength and throwing performance [41, 42]. Monitoring of pitch volume throughout the entire season is important. High pitch volumes in softball pitchers, while not shown to correlate to pitching injuries to the same extent as in baseball pitchers, can lead to a decrease in pitch velocity as well as muscular fatigue ability [39]. Data has revealed the importance of proper preparation as shoulder fatigue, pain, and weakness have been shown after only pitching in 2–3 consecutive days at the adolescent levels [43]. Thus, without appropriate off-season and preseason training and monitoring of pitch volume, the risk of injury increases due to overuse and lack of preparation, as with our patient.

We would also advise that once the pitcher is asymptomatic, a pitching mechanics evaluation should be performed in a sports performance center with three-dimensional analysis, if possible, given data has revealed that improvements in biomechanical flaws can be improved after a video analysis [44, 45]. The combination of a kinetic chain analysis, understanding of the windmill pitching cycle, and the clinical physical examination will allow the medical providers to facilitate safer and more efficient return to play in softball pitchers as well as potentially improve performance and reduce injury risk [45].

Conclusions: Return to Play Criteria

Any throwing athlete, but in particular one who has a great demand placed upon the dominant arm (e.g., a pitcher), must have full active ROM, full strength, and completed a return to pitch throwing program without pain or recurrent

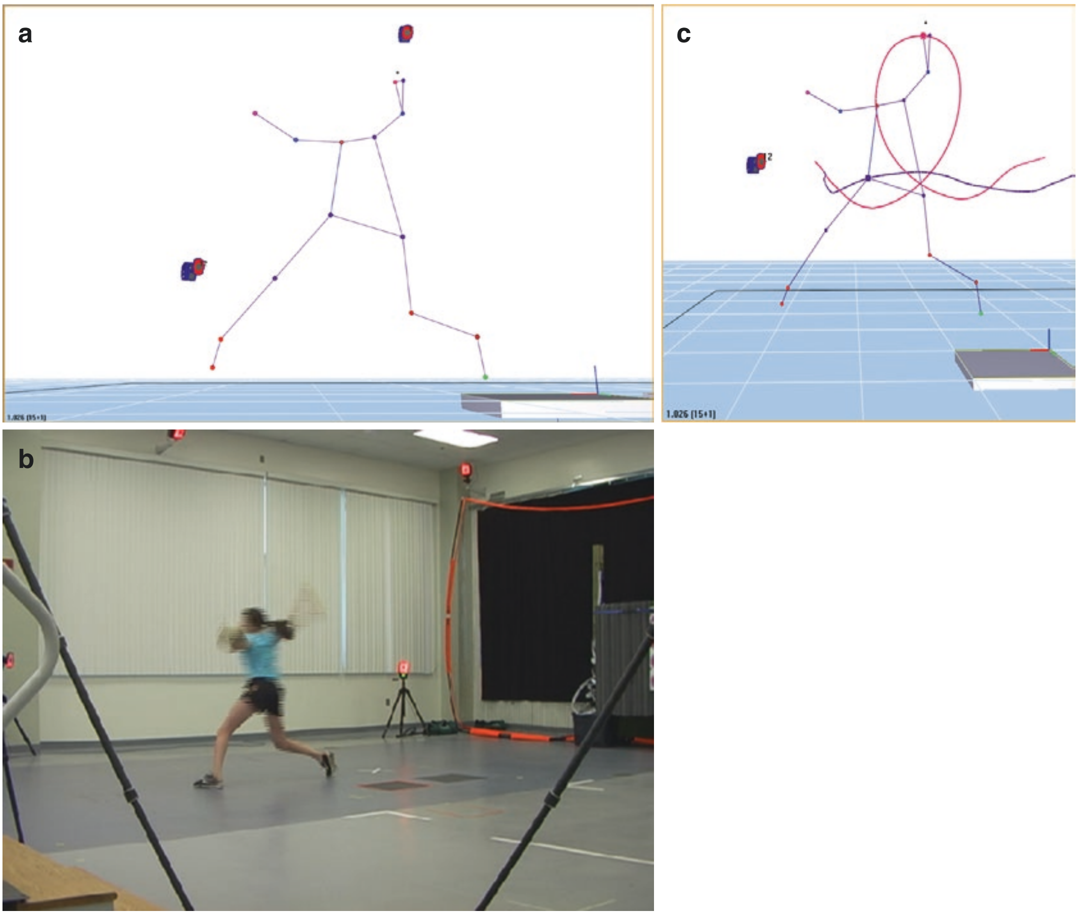

Fig. 14.2 (**a**) Motion capture model of softball player during acceleration to late stride (part 1) of a windmill pitch. (**b**) Reference camera still of image from (**a**). (**c**) Motion marker trajectories of the hip and wrist during a windmill pitch

soreness. In our case, our pitcher was required to complete her return to pitch program without arm pain during the outing, immediately after, or the next day with full-effort pitching. She successfully performed this program and returned to pitching for her high school softball team without a further setback. We have recommended that for future play, our patient participates in an off-season kinetic chain conditioning program, a pre-season pitching program prior to the start of her first practice, and advised to not attempt to pitch through pain.

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A 16-Year-Old Baseball Pitcher with a Sore Elbow

15

Neil K. Bakshi and Michael T. Freehill

Introduction

With the increasing prevalence of sport specialization and the competitive level of today's youth sports, more adolescent athletes are being evaluated for sports-related injuries [1–4]. Some studies suggest that 50% of youth baseball players experience shoulder or elbow pain during their season [5, 6]. Furthermore, rest between seasons has decreased over time, and thus a majority of injuries are due to overuse as young athletes frequently partake in year-round competition and training. The developing elbow is particularly vulnerable to injury in the throwing athlete. In this chapter, we will present a case of a 16-year-old baseball player with a sore elbow and will discuss the pertinent history, physical examination, and many pathologies which could be present.

Case Presentation

A 16-year-old right hand-dominant male baseball pitcher presents with complaints of intermittent medial and posterior right elbow pain over the past 1 month with pitching. He is a year-round competitive baseball pitcher, who also plays the outfield and shortstop. He has hopes of pitching collegiately. He throws a fastball and change-up and has noticed decreased velocity and loss of command of his pitches since the onset of symptoms. The pain presented insidiously and not with one particular throw and no associated "pop." He denies any numbness, tingling, or weakness in the affected extremity. The pain is present at late cocking and in ball release. He denies any previous elbow pain or prior course of treatment for the elbow including physical therapy or injections.

Our standard physical examination always is performed with shirt removed for evaluation of the scapular mechanics. Repeated arm forward flexion is performed to determine pain, weakness, and increasing asymmetry indicative of scapular dyskinesia. With fatigue or pain, the scapula is assisted with pressure over the scapula and pressure across the ipsilateral chest. Improvement in symptoms or strength denotes scapular involvement of the elbow pain. With a protracted scapula, tenderness to the medial border of the coracoid will often be present denoting a tight pectoralis minor. A thorough examination of the shoulder is also performed. This includes comparative motions between sides with particular attention to external and internal rotation of the glenohumeral joint at 90° of abduction. Strength of the rotator cuff, thorough labral and

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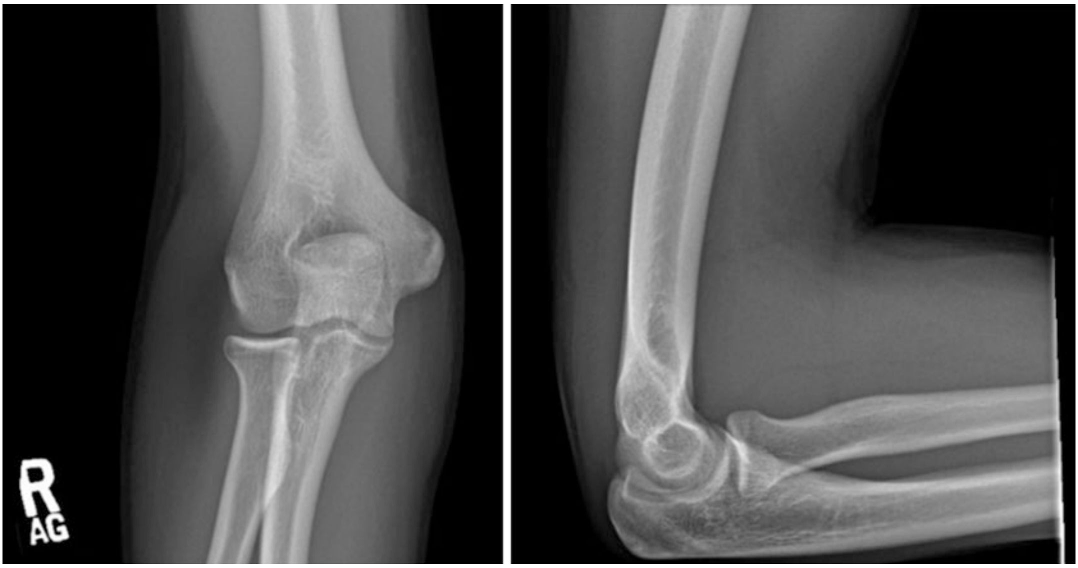

Fig. 15.1 AP and lateral radiographs of the patient's right elbow

biceps examination, as well as differences in latissimus motion while lying supine and the arm brought back over the head are all performed. In the senior author's experience, most of the time, abnormalities of the scapula and at the shoulder are observed, despite an initial complaint of elbow pain. Trunk and core strength and stability are also assessed and again usually demonstrate weakness on initial examination. Our patient demonstrated mild scapular dyskinesia and a rotational deficit of internal rotation of 20°.

On physical examination of the elbow, there is pain with palpation at the medial and posteromedial aspects of the joint. He has 10° of decreased terminal extension in the right elbow compared to the contralateral side. He has pain with valgus stress testing of the right elbow at 20° of flexion to the medial elbow, but no obvious increased joint space opening compared to the contralateral elbow. He experiences pain with the modified milking maneuver and the moving valgus stress test (O'Driscoll's) as well. He also reports posterior-medial elbow pain with forced elbow extension with the arm in supination. All wrist and finger flexors and extensors, as well as hand intrinsics, were full strength. Sensation was symmetric to light touch in all terminal nerve distributions.

Anteroposterior (AP), lateral, and oblique plain films of the elbow were negative for fracture, dislocation, or malalignment (Fig. 15.1). These were compared against plain films of the contralateral elbow. Due to concern for UCL injury, a magnetic resonance arthrogram (MRA) of the right elbow was obtained following the initial visit, which demonstrated mildly increased signal at the undersurface of the humeral attachment of the ulnar collateral ligament on T2 imaging, designating a possible low-grade partial UCL tear. There was no evidence of stress fracture, bony edema, or other pathology on MRA (Fig. 15.2).

Overhead Throwing Motion

While injury to the throwing athlete can occur during any of the phases of throwing, late cocking and early acceleration are associated with a higher risk of injury (Fig. 15.3). It is chiefly during these phases of throwing that the medial elbow is subject to significant valgus forces, resulting in possible tensile pathological insult. Maximum valgus force on the elbow occurs at approximately 90° of flexion during the late cocking phase and can range from 18 to 28 Nm [7–9].

Ossification Centers

The pediatric/adolescent elbow is particularly vulnerable to injury secondary to its open physes. The pediatric elbow contains six ossification centers (capitellum, radial head, medial epicondyle, trochlea, olecranon, lateral epicondyle) that ossify at predictable ages. These centers ossify in the following order: capitellum (age, 1 year), radial head (age, 4–5 years), medial epicondyle (age, 4–5 years), trochlea (age, 8–9 years), olecranon (age, 8–9 years), and lateral epicondyle (age, 10 years). The order of fusion is less predictable, as the capitellum, trochlea, and lateral epicondyle fuse around 12–14 years of age. The radial head and olecranon tend to fuse around 14–16 and 15–17 years of age, respectively. Finally, the medial epicondyle is predictably the last to fuse at ages 16–18 [10, 11]. It is with this in mind that baseball throwers 18 years and less obtain bilateral plain films for comparisons of the fusing physes.

Fig. 15.2 MRA of the right elbow. T2 coronal image demonstrating mildly increased signal at the undersurface of the humeral attachment of the UCL consistent with a possible low-grade UCL tear

Medial Elbow

The overhead throwing motion can result in significant tensile forces across the medial structures of the elbow. Injury to the medial elbow can occur as a result of an acute event or repetitive overuse. These forces can result in a spectrum of pathology at the medial elbow that can affect the physis, ligament, bone, muscle, or multiple structures depending on the weakest region with the tensile stress.

Medial Epicondylar Apophysitis

Medial epicondylar apophysitis, also known as Little League elbow, is a repetitive overuse distraction injury to the medial epicondylar apophysis

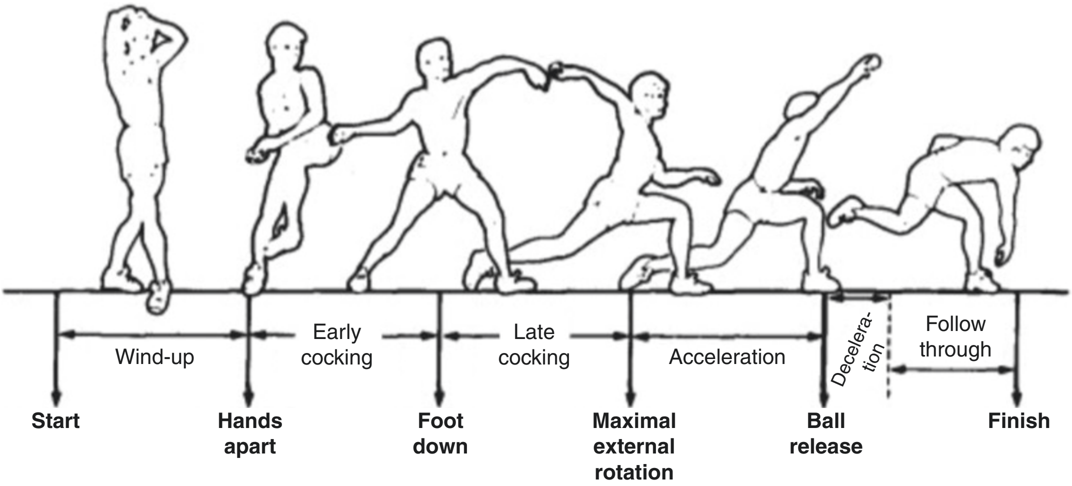

Fig. 15.3 Phases of throwing [8]

caused by the flexor-pronator muscle mass and the UCL [12]. These injuries are relatively common in the 16-year-old baseball player, as the medial epicondyle physis has not yet fused in many of these athletes. Players with medial epicondylar apophysitis will typically complain of progressively worsening medial elbow pain that occurs during the late cocking and early acceleration phases of pitching. These players will also complain of loss of control and decreased throwing velocity. Physical exam findings will usually show swelling and tenderness to palpation over the medial epicondyle, with increasing pain noted with resisted wrist flexion. A slight flexure contracture may also be present [13]. Radiographs may be normal upon initial presentation but often demonstrate widening of the apophysis compared to the non-throwing elbow but can also demonstrate fragmentation, hypertrophy, or deformity of the epicondyle in more chronic cases [14]. Initial treatment of medial epicondylar apophysitis is almost always conservative with throwing cessation for 4–6 weeks, ice, and nonsteroidal anti-inflammatory drugs (NSAIDs), followed by a strength and conditioning therapy regimen. Once a patient’s medial elbow symptoms have resolved with no tenderness on physical exam, a progressive throwing program is initiated [15]. Most players are able to return to play approximately 3 months after the initial injury [16].

Medial Epicondylitis

The tensile forces across the medial elbow can also result in pathology in the flexor-pronator mass itself. Adolescent athletes in whom the medial epicondyle physis has fused are particularly prone to medial epicondylitis. These players present with worsening medial elbow pain with tenderness to palpation over the origin of the flexor-pronator mass. Resisted pronation and wrist flexion will often reproduce symptoms [10]. While radiographs are typically normal, they may demonstrate calcifications or osteophytes in the proximal aspect of the flexor-pronator mass [10]. The initial treatment of medial epicondylitis is conservative and follows the same treatment regimen as that of medial epicondylar apophysitis. Players that do not respond well to noninvasive means can be treated with possible steroid injection for symptom relief and/or rarely surgical debridement.

Medial Epicondyle Fracture

Valgus stresses on the medial elbow along with contraction of the flexor-pronator mass may result in a medial epicondyle avulsion fracture. This is a particularly common injury among athletes with a medial epicondyle that hasn’t fused, as the physis is a site of relative weakness. Players with medial epicondyle avulsion fractures will often have an acute onset of pain and an audible pop at the medial elbow during pitching. Physical exam findings will reveal tenderness to palpation, swelling, and ecchymosis at the medial elbow [17]. Radiographs will reveal displacement of the medial epicondyle. Internal oblique as well as distal humeral axial views can be helpful in determining the location and severity of displacement [18]. Truly non-displaced fractures can be treated non-operatively with immobilization, followed by progressive range of motion and subsequent return to throwing after symptom resolution. However, in the elite pitcher, many recommend surgical intervention for fracture displacement greater than 2–5 mm [19, 20]. Systematic review has demonstrated the return to play with operative fixation is 3.3 months compared to 8.4 months with conservative management [21]. Open reduction and internal fixation of the medial epicondyle fracture can be performed in a variety of ways including screw fixation (Fig. 15.4), Kirschner wire (K-wire) fixation, or suture repair. Furthermore, the medial epicondyle fragment can be excised, followed by suture repair of the medial elbow soft tissues [21]. At our institution, the majority of operative cases are performed using open reduction with a screw +/− washer fixation.

Fig. 15.4 AP radiographs of the throwing (**a**) and non-throwing elbow (**b**) of an adolescent 14-year-old baseball pitcher demonstrating an avulsion fracture of the medial epicondyle. This patient underwent cannulated screw fixation, and 6-week postoperative radiographs (**c**, **d**) show healing of the fracture site

Ulnar Collateral Ligament (UCL) Injury

The UCL is the primary static stabilizer to valgus stress at the elbow with the anterior bundle of the UCL being the primary contributor to valgus stability from 20° to 120° of elbow flexion [22]. Ulnar collateral ligament injury typically occurs in the late cocking and early acceleration phases of throwing and can be secondary to weakness of the flexor-pronator mass, the primary dynamic stabilizer at the medial elbow. Tightness in shoulder internal rotation and excessive shoulder external rotation have also been shown to be associated factors [5, 10]. Players will often complain of medial elbow pain with pitching and throwing, in addition to loss of velocity and/or control. Physical examination will often reveal swelling, ecchymosis, and tenderness to palpation over the UCL. Valgus stress testing at 30° of elbow flexion can also demonstrate pain, increased opening of the medial joint space, and/or lack of a firm end point. Additional physical exam maneuvers including the moving valgus stress test (O'Driscoll's) and modified milking maneuver can also reveal UCL injury [10].

Radiographs are often normal but may reveal an avulsion fracture fragment off of insertion sites of the UCL. Chronic cases may reveal calcifications within the body of the UCL. In addition, dynamic ultrasound can be utilized to demonstrate medial joint space widening or UCL tearing but is largely dependent upon the skills of the operator [23]. Advanced imaging can be performed with computed tomography (CT) or magnetic resonance imaging (MRI) with or without the use of intra-articular contrast. Timmerman et al. prospectively compared CT arthrogram and MRI without contrast and reported that CT arthrogram had a sensitivity of 86% and a specificity of 91%, whereas non-contrast MRI had a sensitivity of 57% and specificity of 100% for the diagnosis of UCL pathology [24]. Schwartz et al. examined the efficacy of MR arthrogram in the diagnosis of UCL pathology and reported 92% sensitivity and 100% specificity, with a higher sensitivity for complete tears (95%) than partial tears (86%) [25].

Treatment of UCL pathology can vary depending on the extent of injury. For partial UCL tears, non-operative management can be initiated, with a period of throwing cessation, NSAIDs, improvement in shoulder and elbow range of motion, and a subsequent interval throwing program when symptoms resolve. Furushima et al. reported successful results with non-operative management of partial UCL tears in baseball players, with an 82% rate of return to competitive play [26]. Although it is an emerging form of treatment with little high-quality evidence to support its efficacy, Dines et al. reported that platelet-rich plasma (PRP) can be an effective treatment for partial UCL tears that have failed conservative treatment. They reported PRP injections in 44 competitive baseball players with partial UCL tears that failed other conservative management and reported that 73% of these players had good to excellent outcomes [27]. Failure of non-operative treatment is typically managed with formal UCL reconstruction [28]. While complete UCL tears can be treated with initial non-operative management, most require formal UCL reconstruction if they desire to return to a competitive level of play [26]. Ulnar collateral ligament reconstruction was initially described by Jobe in 1986, with several alternative techniques being developed in recent years [28–31]. Andrews et al. proposed the technique in which the flexor-pronator muscle mass is reflected medially and a subcutaneous ulnar nerve transposition is performed [29]. The modified Jobe technique is a muscle-splitting approach, through the flexor carpi ulnaris, with ulnar nerve transposition not being routinely performed [31]. The docking technique uses the muscle-splitting approach described above [31] and docks the graft into a single humeral tunnel and is tied over the medial epicondyle [30]. A more recent technique describes repair with heavy nonabsorbable suture tape backing up the repair [32]. This technique is not recommended with mid-substance tears, and though a promising technology, longer-term follow-up studies are still needed.

Ulnar Neuropathy

Many patients with the abovementioned injuries also present with ulnar nerve symptoms. Valgus stress across the medial elbow can place tensile forces across the ulnar nerve resulting in ulnar neuritis. Furthermore, tensile stress on the other medial soft tissue structures can create swelling and inflammation, resulting in subsequent compression of the ulnar nerve. These patients will complain of pain at the medial elbow, along with numbness, burning, paresthesias, and weakness in the ulnar nerve distribution. The athlete may also complain of worsening pain with the elbow in a flexed position. Often, these patients will present with a positive Tinel's sign at the medial elbow and occasionally a positive Froment's sign. In severe cases, patients will present with a positive Wartenberg's sign, which consists of involuntary abduction of the small finger, secondary to unopposed action of the extensor digiti minimi. The physical exam should also evaluate for subluxation of the ulnar nerve with elbow range of motion. While ulnar neuropathy is typically diagnosed with history and physical exam findings, electromyography and ultrasound can also aid in the diagnosis. Treatment of ulnar neuropathy in the adolescent baseball player should proceed with initial non-operative management consisting of throwing cessation, ice, NSAIDs, and an extension brace, while sleeping could improve symptoms as well. This can be followed by an interval throwing program after symptoms have resolved. Patients that do not experience symptom resolution with non-operative management may undergo ulnar nerve decompression with or without transposition [33].

Lateral Elbow

While valgus stress during the overhead throwing motion results in distraction at the medial elbow, there are significant compressive and rotatory forces borne by the radiocapitellar joint. This can result in pathology at the lateral aspect of the elbow, including osteochondritis dissecans (OCD) of the capitellum. Osteochondritis dissecans is an idiopathic, focal abnormality of the cartilage and subchondral bone at the capitellum that can result from the extreme compressive forces seen by the radiocapitellar joint with repetitive pitching. Although the exact etiology of capitellar OCD lesions is unknown, many have suggested recurrent microtrauma and/or vascular insufficiency to be contributing causes. Osteochondritis dissecans of the capitellum typically presents in adolescent overhead athletes between 12 and 17 years of age, commonly with a history of overuse.

Players will complain of insidious onset of lateral elbow pain that worsens with activity and improves with rest. Loss of full elbow extension is often observed as an early sign of a capitellar OCD lesion but will rarely have limitations in elbow flexion or pronation/supination [34–36]. Players may also complain of catching, locking, and grinding symptoms if the lesion has detached. On physical examination, swelling and tenderness to palpation over the radiocapitellar joint are commonly present [34, 36]. The active radiocapitellar compression test can also aid in the diagnosis of a capitellar OCD lesion. During this maneuver, the elbow is fully extended in front of the patient, who then actively pronates and supinates the forearm. Dynamic muscle contraction compresses the radiocapitellar joint and can reproduce symptoms [34].

Imaging for diagnosis of a capitellar OCD lesion starts with multiple-view elbow radiographs. These will often demonstrate capitellar radiolucency and articular flattening. In the chronic or more advanced setting, radiographs will demonstrate fragmentation, sclerosis, or loose body formation. Magnetic resonance can also be a helpful diagnostic tool, particularly in the setting of an early OCD lesion with normal or subtle radiographic findings, and can provide further detail regarding the size, location, and stability of the OCD lesion [34–36].

For stable lesions, non-operative treatment should be trialed initially and consists of throwing cessation, anti-inflammatory agents, and range of motion exercises. Severe cases can be treated with a short period of elbow immobilization. Once symptoms have resolved and there is documented healing of the lesion on radiographs, the player can be started on an interval throwing program with gradual return to play [34, 37].

For patients with symptomatic loose bodies, unstable lesions, or failure with non-operative management, surgical intervention is typically indicated. This can include a variety of interventions including OCD drilling (transarticular or extra-articular), microfracture, fixation of the lesion, debridement with loose body excision, or cartilage restoration with autograft or allograft reconstruction. For skeletally immature patients with stable lesions that have failed non-operative management, OCD drilling can be performed with good results. If the cartilage is intact at the location of the lesion, extra-articular drilling is preferred in order to avoid damaging the articular cartilage. McManama et al. reported on 15 patients with capitellar OCD lesions (ages 13–21) who underwent open excision, abrasion chondroplasty, and drilling of the capitellum. At an average follow-up of 2 years, 13 of 14 (93%) had good or excellent results with return to sport [36]. For unstable lesions with underlying, intact bone, open reduction and fixation can be performed with a variety of methods with good results. For larger capitellar lesions with little underlying bone or healthy cartilage, autograft or allograft reconstruction may be required [38, 39].

Posterior Elbow

Valgus Extension Overload

Elbow stability to valgus stressduring the pitching motion is primarily provided by the anterior bundle of the UCL, along with secondary stability from the flexor mass, the radiocapitellar joint, and also the olecranon/olecranon fossa articulation. As the ulnohumeral joint nears full extension, the relative contribution of the olecranon/olecranon fossa articulation to valgus stability increases. With increased laxity at the medial elbow (i.e., UCL pathology, flexor-pronator weakness), repetitive shearing of the olecranon in the olecranon fossa can occur, resulting in osteophyte formation in the posteromedial olecranon fossa. These osteophytes can fracture and result in loose body formation in the elbow [40, 41].

Players will typically complain of posteromedial elbow pain at ball release and during the deceleration phase of pitching. On physical exam, players may present with tenderness to palpation at the posteromedial aspect of the elbow, as well as a loss of terminal elbow extension in the dominant arm. In addition, patients may complain of pain with forced elbow extension. Specific testing for valgus extension overload can be performed by placing a valgus stress on the elbow at 20° of elbow flexion and then forcing the elbow into terminal extension. This maneuver will commonly reproduce the symptoms that players experience while pitching [40, 41].

Multiple-view elbow radiographs, including oblique views, should be performed to evaluate for valgus extension overload and other related pathologies. Posteromedial osteophyte formation at the olecranon/olecranon fossa, along with history and physical exam findings, can help to confirm a diagnosis of valgus extension overload. However, the absence of posteromedial elbow osteophytes does not exclude a diagnosis of valgus extension overload, as posteromedial elbow symptoms begin prior to the appearance of osteophytes. While MR imaging is not necessary for the diagnosis of valgus extension overload, it can aid in the diagnosis of concomitant pathology, such as UCL injury [40, 41].

Conservative treatment is attempted initially, prior to any operative intervention. This consists of a period of rest, NSAIDs, evaluation and possible correction of pitching mechanics, and strengthening/conditioning. Emphasis should be placed on improving eccentric strength of the elbow flexors, as well as strengthening of the flexor-pronator mass. A gradual return to throwing is attempted with a supervised progressive throwing program after symptoms have resolved [42]. If non-operative treatment fails, arthroscopic or mini-open debridement of the posterior aspect of the elbow may be required. Synovial debridement, osteophyte resection, and removal of loose bodies should be performed with care taken to avoid injury to the nearby ulnar nerve. Postoperatively, players can begin early active elbow flexion and extension. Six weeks postoperatively, patients can begin a progressive throwing program, as symptoms allow. Players can return to play approximately 3–4 months following surgery, assuming adequate progression in the throwing program [42].

Olecranon Stress Fractures

Olecranon stress fractures in the overhead throwing athlete occur secondary to forced elbow extension during pitching. During deceleration, eccentric, tensile stress from the triceps tendon can result in transverse olecranon stress fractures. Furthermore, repetitive microtrauma and posterior impingement of the olecranon in the olecranon fossa (valgus extension overload) often result in oblique olecranon stress fractures in the overhead athlete. In athletes with an open olecranon physis, these repeated stresses during pitching can result in physeal widening, apophysitis, and an unfused olecranon apophysis [40, 42, 43].

These players will complain of posterior elbow pain during and after pitching. They will typically experience symptoms during the deceleration and follow-through phases of the throwing motion. Players may also complain of swelling, weakness, decreased range of motion, and loss of control/velocity. On physical exam, players will complain of tenderness to palpation at the olecranon, as well as increased pain with resisted elbow extension (due to traction from the triceps). The extension impingement test is a physical exam maneuver that can elicit the symptoms experienced with an olecranon stress fracture. This is performed by forcing the elbow into full extension, causing the olecranon to impinge on the olecranon fossa [10, 40, 42].

Multiple-view elbow radiographs should be obtained to evaluate for olecranon stress fractures. While radiographs may demonstrate an olecranon stress fracture or widening/disturbance of the physis, they are normal in many cases. If an olecranon stress fracture is seen, attention should be paid to the orientation of the fracture (transverse versus oblique), as this can influence treatment decision-making. Contralateral elbow radiographs should be obtained for comparison, especially if concerned for physeal widening. Advanced imaging with MRI, CT, and/or bone scan can help in the diagnosis of olecranon stress fractures, particularly if radiographs are negative or equivocal with clinical suspicion [10, 40, 42, 43].

Treatment for olecranon stress fractures and apophysitis varies depending on patient and provider preferences, with some centers being more aggressive with operative management compared to others. Some will initiate a 3–6-month course of non-operative management with rest, throwing cessation, activity modification, and subsequent physical therapy. A bone stimulator can also be beneficial in order to obtain complete bony union. After complete radiographic union and symptom resolution, a gradual return to activity and a progressive throwing program can be initiated, followed by return to competitive pitching. If symptomatic relief and radiographic healing are not achieved, operative intervention can be performed with a variety of methods. Open reduction and internal fixation with a plate, single-cannulated compression screw, or tension

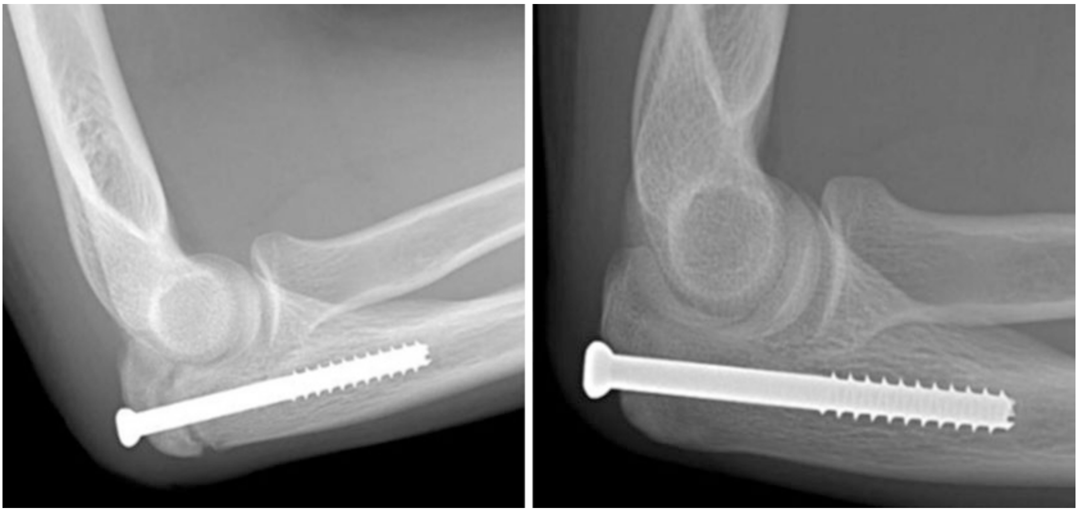

Fig. 15.5 Open reduction internal fixation of olecranon stress fracture with single compression screw with initial postoperative film (left) and follow-up film at 3 months postop (right)

band construct with wire can be performed with successful results (Fig. 15.5). In the throwing population, the single-screw technique is generally preferred. Postoperatively, active elbow extension is restricted for approximately 6 weeks due to distraction at the fracture site with triceps contraction [40, 42, 43]. While surgery may lead to more expeditious return to play for patients with olecranon epiphyseal stress fractures and persistence of the olecranon physis, the indication for surgery remains unclear.

Case Revisited

Based on the history, physical exam, and imaging findings, a diagnosis of valgus extension overload with UCL strain versus low-grade tear was made. Our physical exam findings of decreased terminal extension, pain with forced elbow extension, as well as posterior-medial elbow pain with palpation are consistent with this diagnosis. Furthermore, medial-based pain with valgus stress maneuvers is consistent with a right elbow UCL pathology. Correlation to radiographs and advanced imaging assisted in confirmation of the diagnosis. The athlete did demonstrate mild scapular dyskinesia and tight posterior glenohumeral capsule.

Initial treatment was non-operative management consisting of throwing cessation, activity modification, ice, and anti-inflammatory agents. Physical therapy for strength and conditioning is initiated. Emphasis was placed on obtaining full elbow range of motion and strengthening of the flexor-pronator mass, as this is an important dynamic stabilizer of the medial elbow. Core strengthening was also performed with scapular stabilizer strengthening and posterior glenohumeral capsular stretching. After symptoms resolved, a progressive interval throwing program was started. Once the player graduated from the progressive throwing program (3–4 months after initial onset of symptoms), he returned to competitive pitching. He was instructed in a maintenance program of stretching and strengthening to decrease the risk of future symptoms.

Conclusion

In the adolescent baseball pitcher, the significant forces imparted on the elbow during the pitching motion can result in tensile stress at the medial elbow, compression at the lateral elbow, and shearing/impingement at the posterior elbow. This results in a variety of pathology at these different locations that can result in pain, mechanical symptoms, and loss of control/velocity, significantly limiting a pitcher's participation in competitive baseball. While a few of these injuries may require operative management, the majority of these athletes can be treated with throwing cessation, anti-inflammatory agents, and progressive physical therapy. Once a player's symptoms have resolved, he can begin a progressive interval throwing program, followed by a return to competitive pitching.

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A 18-Year-Old Male Thrower with Acromioclavicular Joint Injury

16

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History

An 18-year-old right hand-dominant male two-sport (football and baseball pitcher) collegiate athlete presents to the office after being tackled and falling directly onto the lateral aspect of his R shoulder in a football game last night. It is early in the season. He reports significant pain at his right shoulder with majority of discomfort located at the superior anterior aspect of his shoulder and the anterolateral deltoid. His symptoms are exacerbated with attempted range of motion beyond the level of his shoulder. He has difficulty with reaching behind him for his backpack but is otherwise able to perform lightweight activities in front of his body and below the level of his shoulder. He denies any prior injury to this shoulder. He also denies any associated numbness/tingling about the shoulder and right upper extremity. He reports no injury or pain throughout the remainder of his right upper limb, and he denies pain in his neck.

Comprehensive Local and Distant Physical Exam

Physical examination of a patient with a suspected shoulder injury demands examination of the entire extremity involved and most importantly the adjacent joints: the cervical spine and elbow. Our typical physical examination steps and the corresponding findings for this patient are described below.

Cervical Spine Exam

Beginning with the cervical spine, evaluation is found to be within normal limits. There is no tenderness to palpation about spinous processes or paraspinal musculature. He has full range of motion about his neck. Spurling's test is negative.

Shoulder Exam

On examination of the patient's right shoulder, moderate asymmetry is appreciated in the contour of the superior aspect as compared with his uninjured, contralateral shoulder (Fig. 16.1). A notable prominence is visible at the lateral end of the clavicle. The overlying skin is intact without sign of abrasion, but some evolving ecchymosis is noted.

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Fig. 16.1 Male athlete with right shoulder acromioclavicular joint injury

Sensory and Motor Exam

Sensory examination of the right upper extremity reveals intact sensation to light touch in the C5–T1 distributions. Radial and ulnar artery peripheral pulses are palpable and symmetric with the contralateral, uninjured upper extremity. He is able to perform an "A-Okay" sign, a thumbs-up, and crisscrossed fingers indicative of intact motor function about his anterior interosseous, posterior interosseous, and ulnar nerves, respectively.

There is no tenderness to palpation about the hand, wrist, and elbow. Active wrist range of motion is full at 70° wrist extension and 75° wrist flexion. Active elbow range of motion is full at 0–130° of extension to flexion and 75° pronation and 85° supination. Strength testing reveals 5/5 wrist extension/flexion, forearm supination/pronation, and elbow extension/flexion. The elbow is stable to valgus and varus stress testing at 30° of flexion.

Acromioclavicular Joint Exam

On evaluation of the right shoulder, he is tender to palpation about the site of deformity, which is the acromioclavicular (AC) joint. To best evaluate this joint, it is helpful to understand the relevant anatomy, physiology, and mechanics.

Anatomy

Two distinct entities contribute to the stability of the acromioclavicular articulation: the acromioclavicular joint and the coracoclavicular interval. Deficiency in one or both of these components compromises the integrity of the essential link between the scapula and the clavicle, which is the singular strut connecting the upper limb to the axial skeleton.

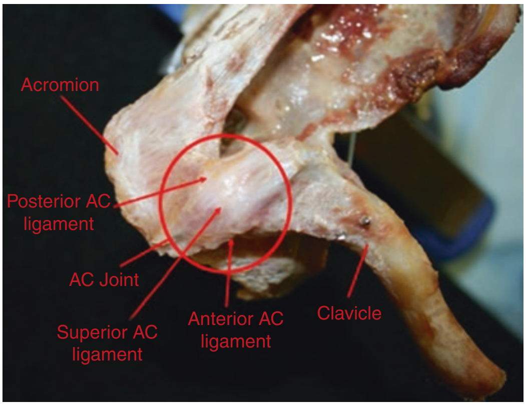

Fig. 16.2 Cadaveric dissection of a right shoulder acromioclavicular joint

Acromioclavicular Joint

The AC joint is located between the anteromedial aspect of the acromion and the distal aspect of the clavicle with a typical joint capsule, intracapsular synovium, and hyaline cartilage-covered bony surfaces. Within the joint space, a meniscal homologue in the form of a fibrocartilaginous disc rests interposed between the ends of the acromion and clavicle (Fig. 16.2) [1]. This joint is stabilized by a combination of static and dynamic structures. The static elements consist of the AC capsuloligamentous structures (superiorly, posteriorly, inferiorly, and anteriorly), which are the primary restraint to anteroposterior translation; the coracoclavicular (CC) ligaments, which are the primary restraint to superoinferior translation; and the coracoacromial ligament. The superior AC capsuloligamentous structure also provides restraint to superior translation under small physiologic loads (Fig. 16.2) [2, 3]. While the AC ligaments are traditionally described as discrete structures, recent biomechanical studies emphasize the importance of the AC joint capsule and ligaments as a composite structure that provides rotational stability to this joint [4].

Coracoclavicular Interval

The CC ligaments refer to two distinct structures connecting the coracoid process and the clavicle: the conoid ligament and the trapezoid ligament. The former is located posteromedially on the clavicle and approximately 4.6 mm from the clavicle's distal end. The latter is located more anterolaterally and approximately 2.5 mm from the distal end of the clavicle [5] (Fig. 16.3). Dynamic stabilizers include the surrounding musculature, specifically the deltoid, trapezius, pectoralis major, and serratus anterior [1, 5] (Fig. 16.3).

Physiology/Mechanics

Motion at the AC joint is both rotational and translational – the latter of which is in two planes: anterior/posterior and superior/inferior. Biomechanical studies have shown through isolated sectioning that the posterior and superior AC ligaments provide the most restraint to posterior translation [1]. Again, this is under smaller loads. With increasing load, the conoid ligament becomes the main restraint to superior translation. The coupled actions between these static stabilizers and the dynamic musculature about the AC joint serve as key transition points with regard to scapulothoracic and glenohumeral motion required for upper extremity range of motion and function. Re-establishing this multifaceted anatomy and these biomechanical relationships is paramount to management after injury to this joint – especially in severe variants where all structures are disrupted.

Clinical Exam

Cross-Arm Adduction Test

Specific tests for evaluating the AC joint have been described and were utilized in our patient's physical exam as described subsequently. The cross-arm adduction test (Fig. 16.4) is performed with the patient's affected upper extremity flexed to 90° at the shoulder, while the elbow remains in a fully extended position. The extremity is then adducted across the patient's chest. A positive result is noted if this maneuver elicits pain for the patient about the superior shoulder near the AC joint. It is critical to localize the site of pain elicited with this maneuver, since the majority of patients with generalized shoulder pain will endorse pain with the cross-arm adduction test – however, the pain in these patients often localizes to the glenohumeral joint instead of the AC joint.

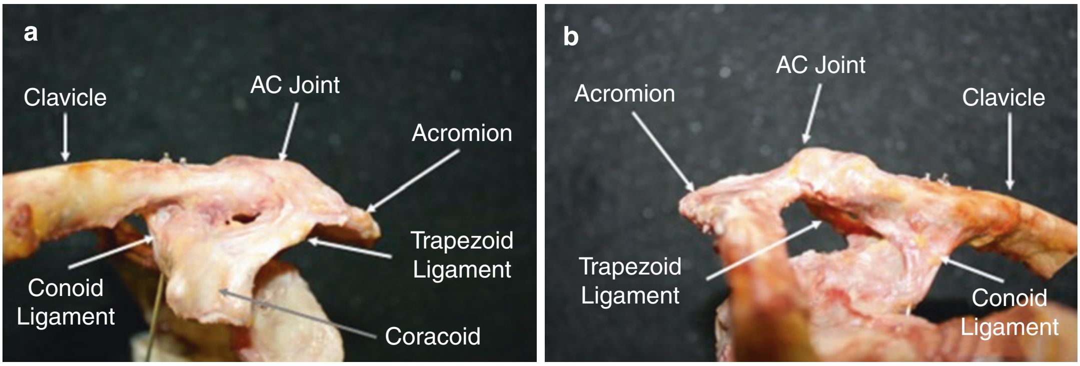

Fig. 16.3 Cadaveric dissection of a left shoulder acromioclavicular joint and coracoclavicular interval: (**a**) anterior view (**b**) posterior view

Fig. 16.4 Cross-arm adduction test. Examiner applies adduction force to patient's upper extremity that is 90° flexed at the shoulder and adducted across the body with full elbow extension. Positive test finding occurs when pain is elicited at the superior shoulder at the AC joint

Fig. 16.5 AC resisted extension test. Examiner provides resistive force to the patient's affected upper extremity from a position of 90° shoulder flexion and elbow flexion and adduction as the patient extends the arm

AC Resisted Extension Test

A second described test is the AC resisted extension test: the patient's affected upper extremity is again flexed to 90° at the shoulder, except, this time, the elbow is also flexed to 90° (Fig. 16.5). Then, the patient is asked to extend their arm against resistance. Once again, if pain is elicited at the AC joint, the test is positive.

O'Brien Active Compression Test

The third commonly used test in AC joint evaluation is the O'Brien active compression test (Fig. 16.6). For this test, the patient's affected upper extremity is flexed to 90° and adducted 10° at the shoulder with the elbow fully extended. The patient is then asked to forward flex/elevate the extremity against resistance with his/her hand in one of two positions: thumb pointing downward versus thumb pointing upward. If the patient notes pain about the AC joint with the thumb pointing downward and this pain is relieved or reduced with testing at the thumb pointing upward position, then the test is considered positive. If the patient notes pain other than the AC joint, the test is considered negative for AC joint pathology. Distinguishing the site of pain with this test is critical since the same test can be utilized to evaluate for superior labral pathology when the pain localizes to the glenohumeral joint instead.

Clinical Test Utility The sensitivity of these tests has been evaluated and found to range from 41% for O'Brien active compression test to 77% for the cross-arm adduction test [6]. The specificity however ranged from 79% for the cross-arm adduction test to 95% for the O'Brien active compression test. The positive predictive value for all tests was found to be less than 30%. However, the diagnostic value for these tests to identify AC joint pathology increased when they were applied and evaluated in combination.

Shrug Test

An additional test utilized is the shrug test as described by Bernard Bach (personal communication 2001). The patient is asked to shrug his/her shoulders, and the affected shoulder is observed for reduction of the AC joint deformity (Fig. 16.7). If reduction is possible with the shrug test, then the likelihood of a higher-grade injury – such as one where the distal clavicle is button-holed through the deltotrapezial fascia or a functionally incompatible displaced injury – is less likely.

Horizontal Plane Test

A final test utilized at our institution is the horizontal plane test. Here, the examiner stands behind the patient using one hand to stabilize the acromion and the opposite hand's index and

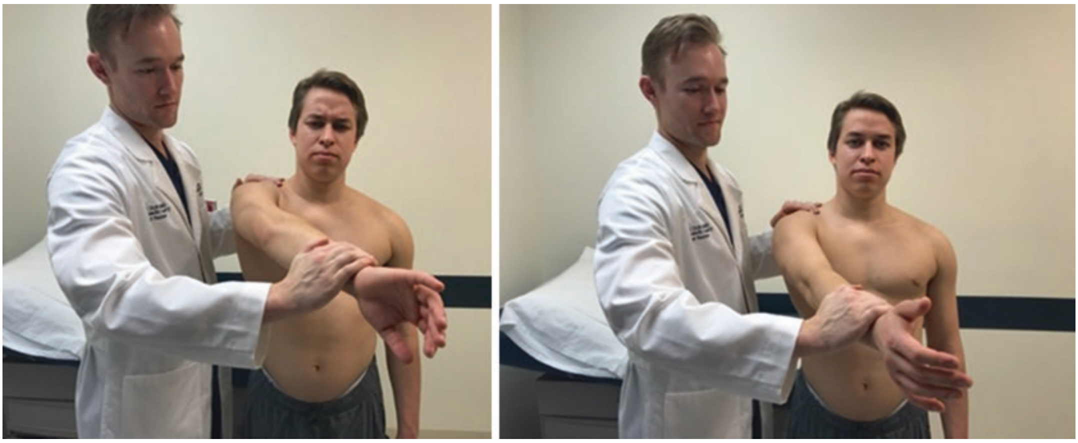

Fig. 16.6 O'Brien active compression test. Examiner applies a downward force to the patient's affected extremity from a 90° forward flexed, elbow extended, and 10° adducted position with the arm in a "thumbs-down" position and then again in a "thumbs-up" position. Pain that is localized to the superior shoulder at the AC joint with the "thumbs-down" position that is relieved in the "thumbs-up position" indicates a positive test

Fig. 16.7 Shrug test. Patient is asked to shrug shoulders and is observed for reduction of AC joint deformity (*please note the individual in the figure does not have AC joint deformity)

thumb to grasp the anterior and posterior aspects of the distal clavicle (Fig. 16.8). Horizontal plane translation is then applied to assess for anteroposterior translation of the AC joint. If such translation is present, this also indicates a higher-grade injury, specifically Grade IIIB as is discussed in the section "Development of Comprehensive Diagnosis" (see Table 16.1). In some instances, the coracoclavicular ligaments may be intact, and a patient may still have a positive horizontal plane test. For this situation, this test helps identify patients who may require more evaluation/treatment due to the instability they often experience during posterior rotation motion activities with the involved shoulder.

Case Patient's Exam

Returning to the patient's exam, his shoulder range of motion is mostly pain-limited to 90° forward flexion, 80° abduction, internal rotation with the arm adducted to L4, and external rotation with the arm adducted to 45°. His uninjured, contralateral shoulder range of motion is full with 175°, 175°, T12, and 90° of flexion, abduction,

Fig. 16.8 Horizontal plane test. Examiner grasps the patient's acromion with one hand and the distal clavicle with the other hand. Anteroposterior force is applied to assess for horizontal plane instability of the AC joint

Table 16.1 Rockwood classification of AC joint injuries with ISAKOS Terminology Project update

Grade	AC joint ligaments	CC ligaments	Clavicular location on radiographs
I	Sprain	Intact	Nondisplaced
II	Disrupted	Intact/ sprained	<25% displacement
III	Disrupted	Disrupted	25–100% displacement
A	Stable – vertical instability, no horizontal instability		
B	Unstable – vertical and horizontal instability, painful exam, weakness, scapular dyskinesis, overriding clavicle on cross-body adduction (Basamania) radiograph		
IV	Disrupted	Disrupted	Posterior displacement into trapezius
V	Disrupted	Disrupted	>100% displaced, non-reducible
VI	Disrupted	Disrupted	Subcoracoid or subacromial clavicle

internal rotation, and external rotation, respectively. During range of motion testing, inspection of the patient's back and scapulae demonstrates right-sided scapular dyskinesis – abnormal and asymmetric scapular motion – that worsens as he nears his extremes of capable active range of motion. Testing is positive for AC joint-specific tests. He has pain localized to the AC joint with cross-arm adduction. On O'Brien active compression testing, there is pain localized to the superior aspect of the shoulder and confirmed with tenderness to palpation at the AC joint during the maneuver. He denies anterior glenohumeral joint pain with O'Brien testing. The prominence about the distal clavicle does reduce with shoulder shrug test. Upon palpation and horizontal plane testing, motion is appreciated around the AC joint with positive horizontal plane test and a positive inferior/superior motion testing.

Imaging

At this time of initial evaluation, the patient is sent for radiographs to further assess his symptoms and physical exam findings.

Standard Radiographs

Our approach includes true anteroposterior (AP), scapular Y, and axillary views of the affected shoulder (Fig. 16.9a–c). When obtaining these radiographs, it is important that the radiology technologists are requested to use a third to a half of the standard x-ray penetration that is typically used for glenohumeral joint exposure. Standard x-ray penetration results in the AC joint being over-penetrated and dark, risking neglect of small or subtle AC joint injuries. These three views with the reduced penetration are important for evaluation of the AC joint and for secondary evaluation of nearby structures such as the glenohumeral joint, scapula, clavicle, and proximal humerus. Evaluating and screening for fracture, Hill-Sachs lesions, bony Bankart lesions, and malalignment, among other bony shoulder pathology, is accomplished with these three views. While generally evident based on history and physical exam, the importance of confirming a reduced glenohumeral joint on an axillary view after traumatic shoulder injury cannot be overstated. The axillary view also helps differentiate a type IV AC joint separation from the other types, since this view will show the distal clavicle located posterior to the acromion/scapula. Such displacement may not be appreciated on an AP view.

Zanca Radiograph

In addition to these three views, Zanca views are obtained of both shoulders on a single x-ray cassette (Fig. 16.9d). This view is obtained by angling the x-ray beam 10–15° cephalad while using only 50% of the standard AP shoulder penetration strength (Fig. 16.10). The Zanca view is the most accurate perspective to evaluate the AC joint since the x-ray beam is projecting onto the joint in the plane of the joint, thereby facilitating adequate evaluation of joint subluxation/displacement. Inclusion of both shoulders on a single image greatly facilitates comparison of the AC joints' anatomy and alignment and the coracoclavicular distances. In cases where the diagnosis is subtle or not readily apparent, the Zanca

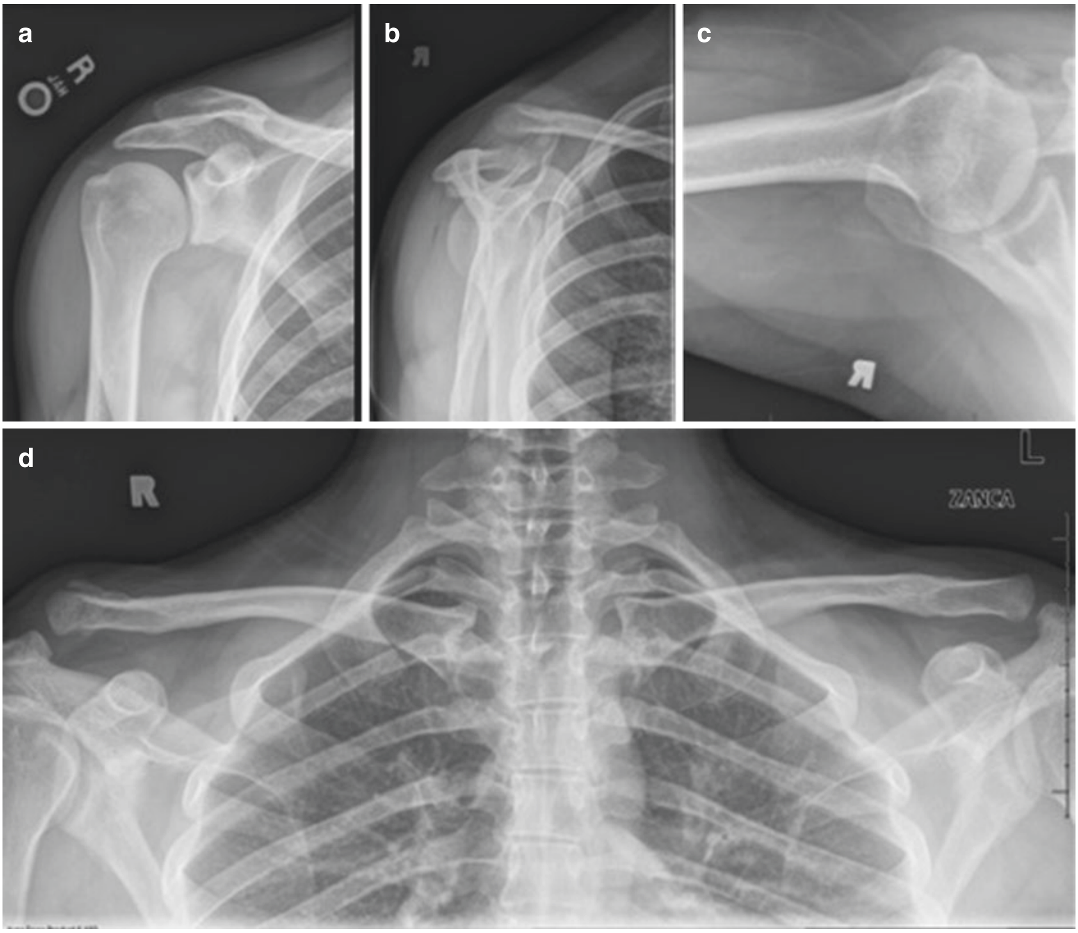

Fig. 16.9 Standard radiographs. (**a**) Anteroposterior view, (**b**) scapular Y view, (**c**) axillary view, and (**d**) bilateral Zanca view

Fig. 16.10 Patient and radiograph beam positioning for obtaining a Zanca view

views can be obtained twice: first, without any weights held in the patient's hands and, second, with weights held in the patient's hands. However, obtaining a weighted view is not as commonplace in practice today, and its diagnostic utility remains debatable [7].

Stryker Notch View

Lastly, if upon review of these images (AP, scapular Y, axillary, and Zanca), there is evidence of an AC joint separation and the coracoclavicular distance is within normal limits (i.e., similar to the contralateral, uninjured side's distance; usually 1.1–1.3 cm [1]), then this raises suspicion for intact coracoclavicular (CC) ligaments in the setting of a coracoid fracture. To further evaluate this pathology, the axillary view should be scrutinized, and/or a Stryker notch view can be obtained. The Stryker notch view is obtained with the patient typically in a supine position with the ipsilateral arm forward flexed overhead and the elbow bent such that the hand supports the back of the patient's head. The x-ray beam is centered over the coracoid process and a 10° cephalad tilt is applied. This view provides visualization of the coracoid and its base.

Advanced Imaging

Further radiographic views or advanced imaging in the form of computed tomography (CT) or magnetic resonance imaging (MRI) is rarely required. Regarding CT, the combination of using a 3D CT with plain films has been found to have poor interobserver and moderate intra-observer reliability for classifying the injury and fair interobserver and moderate intra-observer reliability for determining a treatment method [8, 9].

Development of Comprehensive Diagnosis

Given this patient's visible deformity about the AC joint, tenderness to palpation at the AC joint, positive discomfort with cross-arm adduction testing, and radiographic evidence of asymmetric 25–100% displacement about the AC joint as compared with the contralateral side, the most likely diagnosis is a Grade III AC joint separation. This classification scheme for AC joint separations is credited to Rockwood [10]. Table 16.1 shows a summary of the classification. Zanca view radiographs show displacement indicative of a Grade III injury given that there is slight overlap between the inferior distal clavicle and the superior medial acromion. Furthermore, the patient's physical exam with a reducible AC joint on shrug testing is more suggestive of a Grade III injury. If the AC joint had not been reducible, then the distal clavicle may have been buttonholed through a portion of the deltotrapezial fascia making reduction unfeasible [11]. On physical exam, this patient was noted to have considerable scapular dyskinesis albeit with an element of pain confounding the full evaluation. This dyskinesis matches the suspected diagnosis given that the number of structures disrupted about the AC joint has led to a downward displacement of the patient's scapula and resultantly disrupted scapular mechanics normally maintained with an intact AC joint. The horizontal plane motion test's findings of anterior-posterior mobility and instability push this athlete's diagnosis more toward a Grade IIIB (i.e., unstable Grade III) classification [12]. The grading of this patient's AC joint separation and his demands as a collegiate two-sport athlete with need to restore overhead throwing are all factors that play into treatment clinical decision-making [11, 13].

Plan for Content and Timing of Interventions for Treatment

Timing

This athlete's Grade IIIB injury warrants thorough discussion regarding his options for the remainder of his football season and his plans in the upcoming baseball season. At present and in our hands, recommendations for patients with Grade III injuries favor an initial 3–4-week trial of conservative management [11, 12, 14, 15]. While this athlete is counseled that the "B" subclassification of his injury connotes a higher-grade injury that may ultimately warrant surgical stabilization, he can, and should, reasonably attempt conservative treatment first especially if he desires to play again in this current football season.

Conservative Management

Initial Strategy

The goal of treatment for any grade AC joint injury is a pain-free shoulder with full range of motion and functional stability that meets the patient's demands for desired activities. Initially a period of immobilization and support with a simple sling is commonly employed. This reduces stress on the AC joint, effectively decreasing pain and inflammation. Patients are tasked with discontinuing the sling as soon as they have no pain while their arm is unsupported at their side and while performing self-care activities. If pain is exceedingly high and anticipated to likely inhibit effective early rehabilitation, a local anesthetic injection (e.g., lidocaine) may be infiltrated into the soft tissues surrounding the AC joint or may be directed to the AC joint with or without corticosteroid [13, 16]. This was not necessary for this athlete as he reported moderate and acceptable improvement in symptoms with sling application. Early on, conservative treatment focuses on initiating motion exercises within the first week to regain motion and scapular control, which also assists in decreasing pain and facilitating discharge from the sling.

Phases of Rehabilitation

In general, the recommended rehabilitation protocol derives from that described by Gladstone et al. with four phases: (1) pain control with protective scapular motion and prevention of scapular muscular atrophy with isometric exercises; (2) range of motion exercises to restore mobility and introduction of isotonic exercises; (3) advanced strengthening for further stabilization, strength, power, and neuromuscular control; and (4) introduction of sport-specific exercises for full return to play [17]. In the case of the athlete presented here, exercises during the acute and subacute period of the first week can also include lower extremity and core exercises to re-establish and strengthen the kinetic chain. This helps set the patient up for success upon commencing scapular exercises and the later stages of phase 1 and early phase 2.

Midpoint of Rehabilitation: Decision to Continue or Abandon

The entire course of this conservative trial can last anywhere from 6 to 12 weeks, depending on the patient, the injury severity, and treatment goals. Usually, patients who endorse improvement within the first 6 weeks are likely to successfully complete the course of rehabilitation. Upon regaining full, pain-free range of motion and ability to perform sport-specific functions, the athlete is cleared for return to full activity. This milestone was achieved by this athlete in 8 weeks, and he returned to football in late August.

Follow-Up Post-Rehabilitation

In mid-September, the athlete sustained a repeat injury to his right shoulder and re-presented to the office the next day. He reports pain similar to and more severe than his initial injury. He voices concern of being able to play baseball at full capacity with the current state of his shoulder.

Repeat Evaluation and Decision-Making

Examination reveals marked scapular dyskinesis that had been previously improved at the end of his 8-week course of supervised rehabilitation. Repeat radiographs are performed and also specifically include a cross-body adduction view, or “Alexander” view (Fig. 16.11a). This additional view, described by Alexander and also by Barnes et al. (who coined it the Basamania view), may also assist with evaluating for stability in AC joint separations that do not improve as expected with conservative management trial [18, 19]. With the patient’s arm positioned in a cross-body fashion, an AP projection of the AC joint is obtained (Fig. 16.11b). The degree of overlap between the clavicle and the acromion helps determine the stability of the AC joint and the status of the CC ligaments [12, 18, 19]. Overlap of the distal clavicle and acromion suggests a higher-degree injury and confirms the persistent instability of this athlete’s AC separation. Given the patient’s attempt with conservative management; his semi-successful return to activity, albeit temporarily; and his current symptomatic state and clinical exam findings, the patient elects to pursue offered surgical management.

Operative Management

The literature is replete with surgical techniques for managing AC joint injuries, and no single procedure has been identified as the gold standard. Three general categories of surgical strategies are as follows:

- AC joint stabilization
- CC interval stabilization
- Anatomic reconstruction

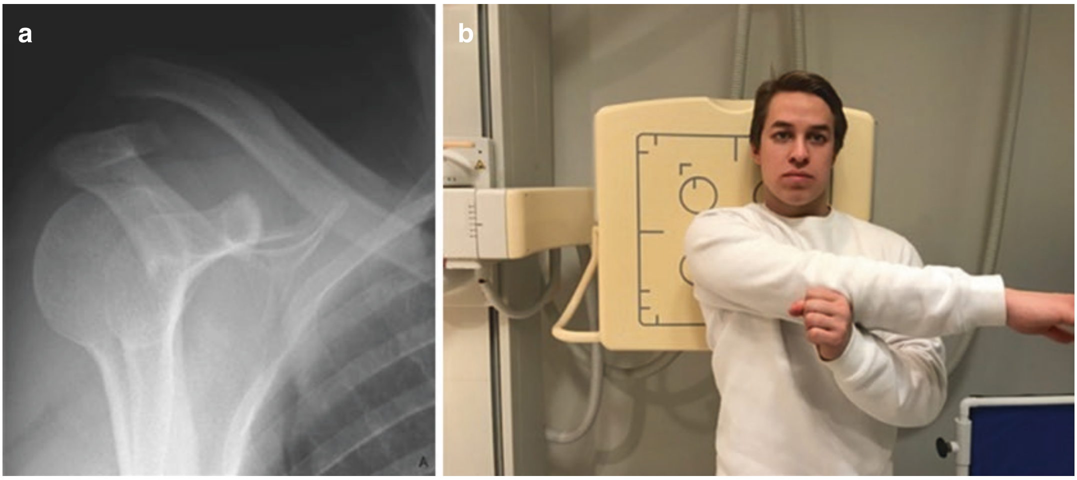

Fig. 16.11 Cross-body adduction view, also known as the Alexander view or the Basamania view. (**a**) Radiograph image, (**b**) patient positioning for obtaining this view

AC Joint Stabilization

Stabilization procedures for the AC joint have historically included pin (smooth or threaded) fixation across the AC joint and hook plate application and attempted repair of the capsular tissue. However, while these constructs did well initially, the necessary inherent motion at the acromioclavicular articulation and across the coracoclavicular interval resulted in hardware breakage and sometimes hardware migration to perilous locations such as the lungs, major cardiac vessels, and spinal column [20–23]. Furthermore, a second procedure is often advised to mitigate these risks of migration and risks of potential hardware failure. Subsequently, the Bosworth screw was introduced as transient fixation, but this proved too stiff a construct and incompatible with AC joint biomechanics restoration.

CC Interval Stabilization

The most well-known coracoclavicular interval stabilization procedure has been that described by Weaver and Dunn. This involves transfer of the coracoacromial (CA) ligament's proximal attachment from the acromion to the clavicle for stabilization [24]. While good results were initially reported with this construct, subsequent studies demonstrated residual subluxation and/or dislocation, and biomechanical studies found inferiority of the CA ligament's load to failure and stiffness in comparison to the native CC ligaments and free tendon grafts [25–30]. Furthermore, Debski et al. demonstrated that AC joint capsular injury transfers significant loads to the CC ligaments, suggesting that CC interval stabilization in isolation may not be adequate [4, 31].

Anatomic Reconstruction

Given historical inadequacy of isolated AC joint stabilization procedures, isolated CC interval stabilization procedures, and biomechanical studies emphasizing the importance of the AC capsule, the senior author's preferred technique entails anatomic CC reconstruction (ACCR) with AC joint capsuloligamentous complex reconstruction. A free tendon graft is looped around the coracoid and then secured to the clavicle at the anatomic origins of the conoid and trapezoid ligaments for ACCR [32]. A dermal patch is used to reconstruct the superior, posterior, and anterior aspects of the AC joint capsuloligamentous complex.

Procedure

Positioning

- The patient is typically positioned in a mild beach chair or recumbent supine position.

Incision

- The incision extends from the coracoid and then posteriorly over the clavicle to end approximately 2.5–3.0 cm medial to the AC joint (Fig. 16.12). Meticulous dissection is required to raise full-thickness flaps for subsequent closure and minimizing risks of postoperative wound complications.

Muscular Interval

- The interval at which the deltoid and trapezius insert onto the clavicle is identified, and flaps of each muscle are developed directly off bone, tagged at the deep fascial layers for later re-approximation, and retracted anteriorly and posteriorly, respectively.

Coracoid Preparation

- Soft tissues are released directly off the medial and lateral aspects of the coracoid to facilitate passage of a passing suture with a curved hook suture passer introduced medially to the

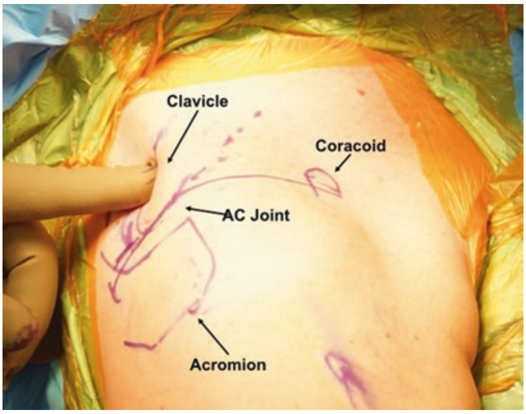

Fig. 16.12 Right shoulder with surface landmarks and planned skin incision

coracoid and curved laterally hugging the undersurface of the coracoid [32].

- A looped passing suture (and, if desired, a high-strength, nonabsorbable, ultrahigh-molecular-weight polyethylene suture) is introduced into the curved hook suture passer and retrieved on the medial side of the coracoid. The curved hook suture passer is removed, while the passing suture (and nonbiologic augmentation, if used) remains in place around the deep surface of the coracoid. Care is taken to maintain this passing suture near the anterior aspect of the coracoid, so the ultimate vector of pull upon final reconstruction is more anteriorly directed and therefore reduces posterior scapuloclavicular instability.

Clavicle Preparation

- The clavicle is marked on its superior surface at 10 mm, 25–30 mm, and 40–45 mm medial to the AC joint (Fig. 16.13 – AC joint capsuloligamentous complex anteroposterior tunnels drilled already in this image with respective looped passage sutures in place). These locations are reamed with a 5.0 mm reamer, taking care to remove the reamer by hand so as to not inadvertently enlarge the tunnel ("ream-in, pull out" technique).

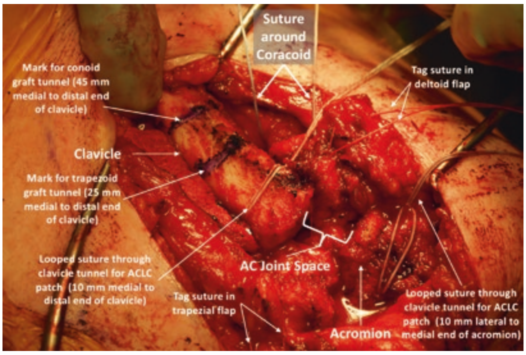

Fig. 16.13 Right clavicle with markings at the 45 mm and 25 mm points from the distal end of the clavicle and looped suture through anteroposterior tunnels (described in *AC Joint Capsuloligamentous Reconstruction* section) in the clavicle and acromion 10 mm from the lateral and medial edges, respectively. Tag sutures are seen here in the deltoid and the trapezial flaps developed during muscular interval dissection. Suture is also seen around the coracoid passed for subsequent CC ligament reconstruction graft passage

- The tunnels are tapped with a 5.5 mm tap, and a looped passing suture is placed in each tunnel with the loop on the deep surface of the clavicles to facilitate subsequent graft passage to the superior surface of the clavicle.

Graft Preparation

- Allograft* or autograft can be used. We prefer allograft to avoid donor site morbidity and the additional positioning issues introduced with harvesting a semitendinosus graft.
- The graft is tubularized at its ends to facilitate smooth passage through the clavicle tunnels by whip-stitching each end with high-strength nonabsorbable suture. This also helps create a snug construct at the ends of the graft to avoid fraying as the graft is passed.
- *Note: If using allograft, it is important to pretension the graft to minimize innate creep in the allograft's collagen bundles.

Graft Passage

- The suture from one end of the graft is introduced into the previously passed looped suture around the coracoid, and the passing suture's tails are pulled to deliver the graft deep to the coracoid.
- Then, the suture* at each end of the graft is passed through its respective loop of the previously placed passing sutures in the clavicle tunnels. The lateral graft limb's sutures will pass into the trapezoid tunnel, and the medial graft limb's sutures will pass into the conoid tunnel. A "u"-shaped construct will be ultimately created.
- *Note: if nonbiologic augmentation suture was passed also deep to the coracoid, then the tails of this suture are passed simultaneously with the graft limb sutures into the clavicle tunnels.

AC Joint Capsuloligamentous Reconstruction

Measurements and Graft Prep

- A line is marked 10 mm lateral to the medial edge of the acromion and is marked in orientation with the native AC joint.
- Measurements are made in a quadrilateral fashion between this line and the line on the clavicle 10 mm medial to the clavicle's lateral

edge: anterior edge distance, medial distance, posterior distance, and lateral distance.

- A 2.4 mm cannulated drill is used to create an anteroposterior tunnel at each 10 mm mark for the medial and lateral edges of the AC joint capsuloligamentous reconstruction. Care is taken to exit the acromion posteriorly at the same level of posterior border of the clavicle.
- Two all-suture anchors or a button loaded with high-strength suture is placed just adjacent to and halfway along the trajectory of the anteroposterior tunnels (Fig. 16.14).
- The dermal patch is prepared by being cut down to size to match the measurements made previously.
- The anterior and posterior edges are whip-stitched with high-strength suture (Fig. 16.15), and the prepared graft patch is checked in the field to confirm appropriate sizing (Fig. 16.16).
- Looped sutures passed through the bone tunnels are used to pass the whip-stitched sutures through the tunnels – for the anterior medial limb passed through the clavicle tunnel from anterior to posterior, the posterior medial limb passed through the clavicle tunnel from posterior to anterior, and similarly the anterior and posterior lateral limbs being passed through the acromion tunnel.

CC Interval Reduction and Graft Fixation

- The conoid limb of the ACCR is secured first. If nonbiologic suture is utilized, it is threaded through the cannulated portion of the interference screw that will secure the conoid limb within its clavicular tunnel.
- Next, the joint is reduced by applying a proximally directed force to the elbow to elevate the scapulohumeral complex to the distal clavicle. An inferiorly and anteriorly directed force is applied to the distal clavicle. This is often performed to the point of over-reduction

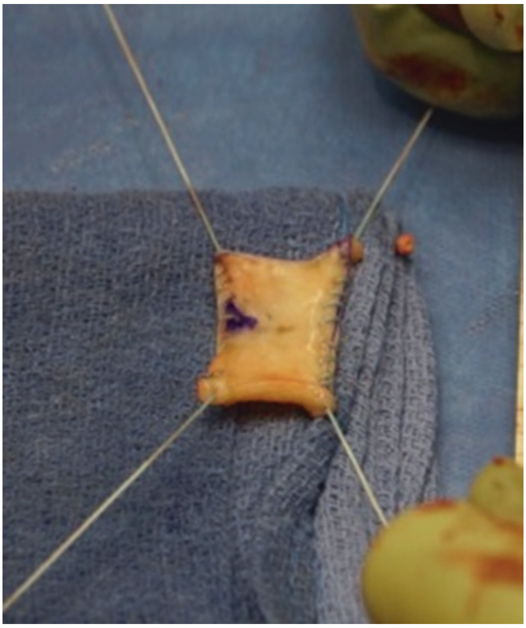

Fig. 16.15 Dermal patch graft prep. The anterior and posterior edges of the graft are whip-stitched with high-strength suture

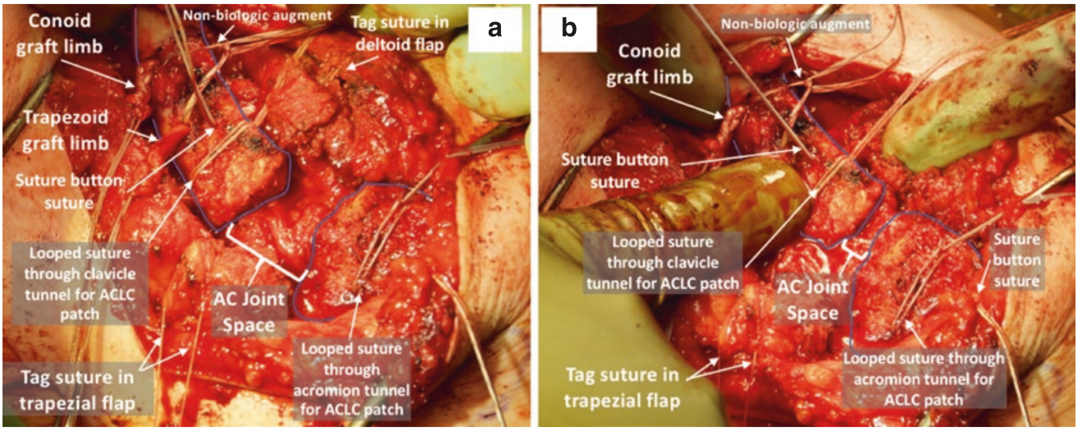

Fig. 16.14 Midpoint fixation points for right shoulder AC joint capsuloligamentous reconstruction with suture button (or all-suture anchor) placed halfway along the trajectory of the anteroposterior tunnels in the clavicle and the acromion. (**a**) AC joint prior to manual reduction, (**b**) AC joint after manual reduction

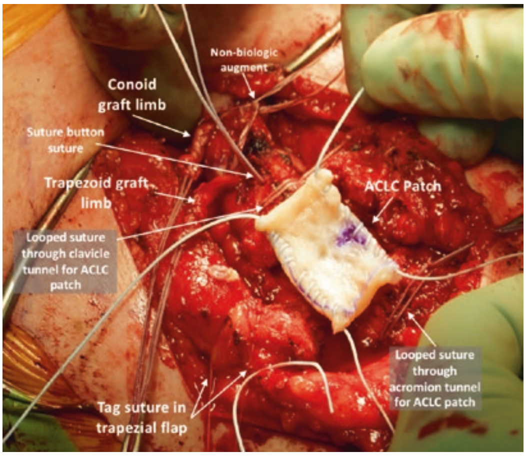

Fig. 16.16 Dermal patch graft placed in surgical field of right shoulder AC joint capsuloligamentous reconstruction to confirm sizing

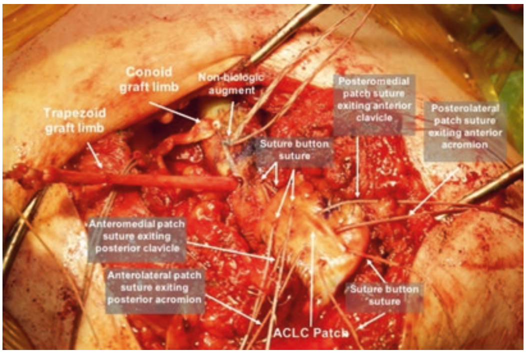

Fig. 16.17 Nonbiologic augment fixation is secured over the bone bridge between the conoid and trapezoid tunnels in the right shoulder ACCR. At this point, the conoid and trapezoid graft limbs are already fixed with interference screw fixation. Shown here, also, the sutures from the anteroposterior tunnels in the clavicle and acromion and the sutures from the midpoint fixation suture buttons are passed through the dermal patch graft for the AC joint capsuloligamentous reconstruction

(Fig. 16.14). Tension is held on the graft, while the trapezoid limb (and nonbiologic suture augmentation) is secured in a similar fashion to the conoid limb.

- The nonbiologic suture augmentation is tied to itself over the bone bridge between the conoid and trapezoid tunnels (Fig. 16.17).

AC Joint Graft Fixation

- The four corner limbs of suture passed through the tunnels of the acromion and the clavicle are passed through the corners of the dermal patch graft using a free needle.
- The button or suture anchor sutures are also passed through the dermal patch graft using a free needle (Fig. 16.17).
- While maintaining over-reduction pressure, the posterior suture limbs are tied together over the patch graft to maintain an anteriorly directed reduction. This is followed by tying the anterior limbs, then the lateral limbs, and finally the medial limbs (Fig. 16.18).

Muscular Interval Closure

- After copious irrigation, the previously placed muscular interval tag sutures are identified, and the deep aspects of the deltoid and trapezius are re-approximated, and the deltotrapezial fascia is closed using the Arciero barrel stitch to create a watertight closure (Fig. 16.19). High-strength suture is used and is passed from outside to inside on the deltoid flap, then outside to inside on the trapezial flap, then inside to outside on the deltoid flap, and finally from inside to outside on the deltoid flap to create overlap upon tying down the suture limbs. Standard layered wound closure ensues, and the extremity is placed in a shoulder brace or sling that supports the arm protecting the repair from the pull of gravity (e.g., Lerman Shoulder Brace, DJO Inc., Vista, CA, or Gunslinger Shoulder Orthosis, Hanger Prosthetics & Orthotics, Inc., Bethesda, MA). A cold therapy unit is also applied to the shoulder.

The anatomic coracoclavicular ligament reconstruction and AC joint ligament/capsule reconstruction technique were selected for treating this 18-year-old athlete's dominant-sided Grade IIIB AC joint separation.

Results of Interventions and Progression of Recovery

Postoperative protocol stems from biologic studies on tendon-to-bone tunnel healing that identified the 12-week postoperative time point as when load-to-failure occurs at the mid-substance

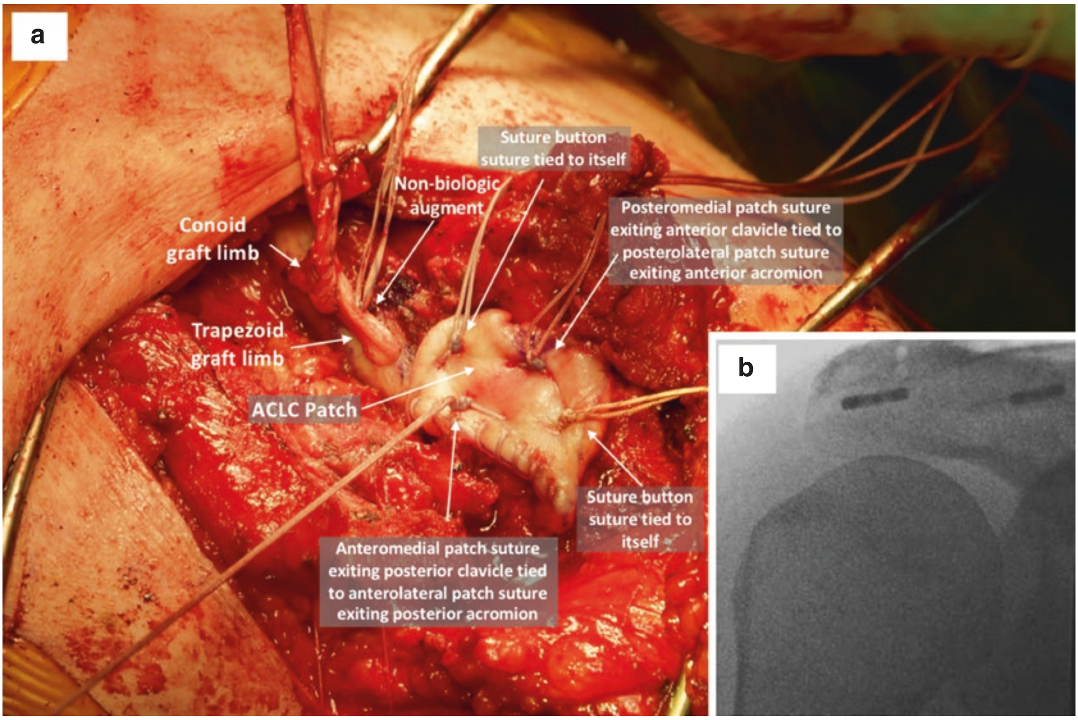

Fig. 16.18 AC joint capsuloligamentous reconstruction in a right shoulder. (**a**) Sutures passing through the dermal patch graft are tied to secure this AC joint capsuloligamentous reconstruction while maintaining manual over-reduction pressure, (**b**) fluoroscopic anteroposterior imaging confirming AC joint reduction and suture button placement

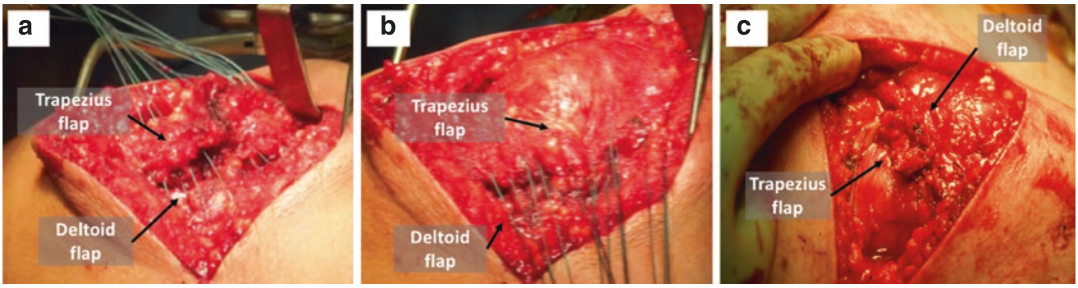

Fig. 16.19 Muscular interval closure. (**a**) The Arciero barrel stitch is used to pass suture in an out-out-in-in fashion through the deltoid and trapezius flaps (**b**) to create overlap upon cinching and (**c**) tight re-approximation of the muscular interval

of the tendon rather than the bone tunnel-tendon interface [33]. The supportive brace or sling is utilized for the first 6 weeks to protect the reconstruction against gravity forces, and it is only removed for daily hygiene. Protective exercises are simultaneously performed with support under the arm (e.g., table or wall) to avoid undue stresses on the reconstruction construct. Exercises are then gradually increased to inclined surfaces and then vertical surfaces. Forward flexion motion is also practiced and is done so in a supine fashion, again to protect the reconstruction. Subsequent progression of exercise advancement follows similarly with the conservative management phases described earlier [17]. Closed-chain scapular and kinetic chain exercises are permitted at 8 weeks postoperatively. Typically, patients achieve nearly full range of motion by 10 weeks postoperatively, with only some limitation in behind-the-back internal rotation. Typical behind-the-back internal rotation stretches are progressively incorporated to the rehab regimen as the patient is able to maintain scapular retraction [16]. Phase 3 with isotonic strengthening exercises is held off until 12 weeks postoperatively. Phase 4 is initiated upon achieving adequate control with Phase 3. Sport-specific exercises are introduced around 4–5 months postoperatively, and return to sport usually ensues anywhere between 5 and 6 months postoperatively depending on each patient's success with the rehabilitation program.

The patient presented here progressed well through his postoperative therapy and was able to return to baseball just as the season started.

Outcomes of Treatment

In the senior author's case series of 17 patients with Grade III or V AC joint separations managed with ACCR alone, there were 3 failures [32]. One patient developed a chronic infection requiring allograft removal and myocutaneous flap for soft-tissue coverage. A second patient reported persistent AC joint pain and underwent a distal clavicle excision, which did not resolve the symptoms. The third patient was considered a failure secondary to a loss of reduction.

Other groups have had similar success with anatomic CC ligament reconstruction management of AC separations. In Tauber et al.'s series of 24 patients with Grade III through V injuries where half underwent a modified Weaver-Dunn procedure and the other half underwent anatomic reconstruction, both clinical and radiographic superiority were seen in the anatomic reconstruction group [34]. Studies by Lee and Bedi and by Millet et al. on outcomes of anatomic CC ligament reconstruction have also found good-to-excellent results [35, 36]. Further modifications of the anatomic CC ligament reconstruction technique have included docking the graft limbs within tunnels in the acromion and incorporating native AC joint capsuloligamentous tissue into a suture anchor repair. A case series of 15 patients with Grade III to V injuries undergoing this modification of the ACCR also had significantly improved patient-reported and clinical outcomes [37].

The inclusion of the AC joint capsuloligamentous complex reconstruction with the ACCR has had good results thus far in the senior author's experience (publication of results forthcoming).

Summary of Conclusions from the Case

Acromioclavicular joint injuries in the young throwing athlete demand a detailed evaluation supplemented with careful radiographic assessment. Grade III injuries can be managed conservatively. However, in a select subset of patients with high demands of their shoulder and/or more severe injuries with a component of horizontal instability (i.e., Grade IIIB), surgical intervention may be necessary. Anatomic CC ligament reconstruction is a biomechanically sound and clinically promising technique for providing these patients with a pain-free, full range of motion and functionally stable shoulder.

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17

Pan Labral Tear in an Overhead Throwing Athlete

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Liam A. Peebles, and Anthony Sanchez

Case Presentation

In this case, an 18-year-old football quarterback and elite college prospect falls onto his outstretched arm while evading a tackler in a game and sustains a pan labral tear. Pan labral tears of the glenoid labrum often cause pain recurrent instability of the shoulder. These tears typically occur due to an acute traumatic event, such as falling onto an outstretched arm, overhead throwing, overhead weightlifting, etc. Degenerative deterioration with aging can also lead to pan labral injury. Pan labral tears are commonly preceded by superior labrum degeneration, especially in overhead throwing athletes [1]. The 18-year-old football quarterback may have been predisposed to a pan labral injury due to previous deterioration of his superior labrum due to the repetitive overhead throwing motion required of football quarterbacks. Thorough patient history, physical examination, and diagnostic imaging are important for accurate diagnosis and treatment of pan labral tears.

Anatomy

The glenoid labrum is comprised of fibrocartilage tissue that circumferentially surrounds the glenohumeral joint of the shoulder. The labrum provides stability to the glenohumeral joint by increasing the depth of the glenoid fossa, limiting humeral head translation, and enhancing the concavity-compression mechanism between the humeral head and glenoid fossa [1]. The superior part of the labrum is morphologically distinct from the inferior labrum in that it consists of a meniscal pattern which stretches easily [2]. The inferior glenoid labrum consists of inelastic fibrous tissue that does not stretch easily [2]. The superior labrum inserts directly into the long head of the biceps tendon distally to where the long head biceps tendon insets into the supraglenoid tubercle [2]. The biceps tendon inserting at this location creates a synovial reflection in which there is a small recess between the tendon and superior glenoid labrum [2]. The superior labrum is prone to tearing due to its anatomic relationship with the biceps tendon and its elastic fibrocartilage tissue.

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Pan labral tears often initiate in the superior glenoid labrum before progressing circumferentially. The superior labrum also receives less vascular supply than other parts of the labrum, which is clinically relevant to the healing process [2]. Rao et al. [3] described three anatomical variations of the anterosuperior aspect of the glenoid labrum that are clinically relevant to effective treatment of a pan labral tear. Overhead throwing athletes are at higher risk of superior labrum tear due to the anatomical characteristics of the superior labrum that make it prone to tear when placed under the stress of repetitive throwing kinematics.

Diagnosis

Pan labral tear diagnosis relies on patient history, physical exam, and magnetic resonance imaging. Pan labral tears are Type IX SLAP according to the Snyder Classification of SLAP lesions [4]. Rao et al. [3] define a Type IX SLAP tear as complete separation of the superior biceps anchor-labral complex and the anterior, posterior, and inferior labra. Patient history and physical examination alone make it difficult to diagnose pan labral tears due to low specificity of the physical exams and the wide variation of patient histories [1]. Magnetic resonance imaging (MRI) and magnetic resonance arthrography (MRA) are the “gold standards” in diagnosing labral tears and making an accurate classification of the SLAP type.

Patient History

History should include mechanism of injury, past shoulder injuries or episodes of instability, patient age, sport activities, job activities, symptoms of pain and instability, and a review of family history in order to rule out connective tissue diseases such as Ehlers-Danlos or Marfan syndrome. Thorough patient history will aid in proper diagnosis and treatment.

Physical Exam

Physical exam should include observation, palpation, range of motion, strength, neurovascular, and provocative tests (anterior apprehension test, anterior load-and-shift test, sulcus sign, posterior jerk test, Kim test) in order to ascertain a broad, systematic examination.

Begin the examination with inspection of both shoulders looking for signs of asymmetry, swelling, and muscle atrophy [5].

Palpation of the anterior and posterior glenohumeral joint lines may reveal tenderness. Tenderness upon palpation is a nonspecific finding that may underlie labral pathology, rotator cuff pathology, or capsular stretch.

Overhead throwers are predisposed to deficits in glenohumeral ROM. Most overhead throwing athletes demonstrate an increase in external rotation and decrease in internal rotation when the arm is abducted 90°, when comparing the throwing arm to the non-throwing arm. The term used to describe this pathophysiology is glenohumeral internal rotation deficit (GIRD). The exam involves the patient being in the supine position and the arm positioned 90° of shoulder abduction and elbow flexion [1]. The provider then measures the amount of internal and external rotation using a goniometer while stabilizing the scapula [1]. An internal rotation deficit of at least 20° is positive for GIRD [1].

Scapular ROM can be assessed through forward flexion in order to discern scapular winging. In addition, scapular depression, anterior tilt, and protraction indicate shoulder dysfunction [1]. Scapular dyskinesis is assessed via examining the elevation and depression of the arm.

The Gagey hyperabduction test assesses the glenohumeral joint range of abduction. A range of passive abduction greater than 105° indicates lengthening and laxity of the inferior glenohumeral ligament [6]. The test is performed with the examiner positioned behind the seated patient. The examiner firmly places his forearm on the patient’s shoulder girdle while the examiner’s other hand lifts the patient’s relaxed arm in abduction. The patient's elbow is flexed 90°, and the forearm is in the horizontal plane. A goniometer is used to measure the range of abduction.

Provocative tests are performed to assess various directions of instability.

Inferior instability is assessed using the sulcus sign. The patient is sitting upright with shoulder in the neutral rotation and arm resting at patient's side. Axial traction is applied to the upper arm, and the amount of inferior subluxation is measured with regard to the distance between the humeral head and acromion [7]. The distance of inferior subluxation is given a grade of 1–3 (Grade 1 is a distance of 1 cm or less, Grade 2 is 1–2 cm, and Grade 3 is greater than 2 cm).

The anterior apprehension test assesses anterior instability. The test is performed with the patient in the supine position and the shoulder at 90° abduction while in maximal external rotation [8]. Reproduction of the patient's apprehension symptoms indicates anterior instability while in this position. The anterior load-and-shift test can also be used to assess anterior instability. With the shoulder in the neutral anatomical position, the examiner applies an anterior directed force by holding the head of the humerus with one hand while stabilizing the scapula with the other hand. Production of pain or a palpable clunk is a positive sign of anterior instability [9].

Posterior instability can be evaluated via the jerk test. The jerk test has the patient either standing, supine, or in the lateral decubitus position. The examiner holds the patient's elbow with the arm in 90° forward flexion and internal rotation. The examiner's other hand stabilizes the patient's scapula by holding the distal clavicle and scapular spine. The flexed elbow is pushed posteriorly while the shoulder girdle is pushed anteriorly. The jerk test is positive if it renders a sudden jerk of the humeral head posteriorly over the glenoid rim. A positive jerk test can also be ruled by reproduction of patient symptoms [5]. Another provocative test to determine posterior instability is the Kim test. The patient is seated and the arm is abducted 90°. The examiner holds the patient's elbow and lateral aspect of the proximal arm while applying an axial loading force: a 45° upward diagonal elevation to the distal arm and an inferior-posterior force to the proximal arm. The arm is then adducted. Sudden posterior shoulder pain is a positive Kim test result.

Imaging

MR arthrography (MRA) is the gold standard for detecting labral tears. MRA is the best imaging modality for evaluating soft-tissue structure of the shoulder. MRI can be used in the diagnosis of pan labral tears but often underestimates the extent of the tear [3]. MRA views reveal structural pathology relating to circumferential labral tears.

The MRI images below are of an 18-year-old football player who sustained a left shoulder labral tear while playing in a football game and had numerous instability events over the course of an 18-month period (Figs. 17.1 and 17.2).

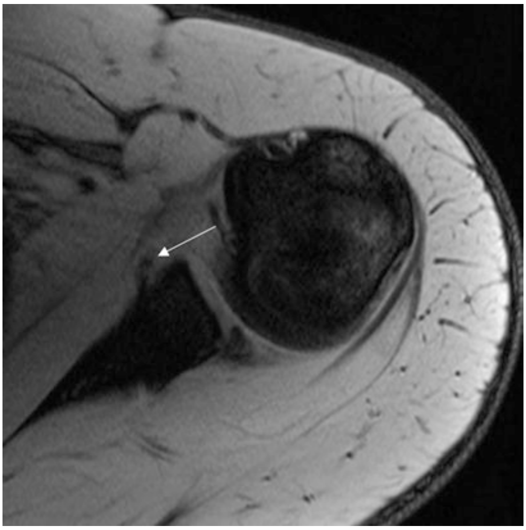

Fig. 17.1 Left shoulder; labral tear anterior, inferior, and posterior with a small ALPSA component (arrow indicates ALPSA tear)

Fig. 17.2 Left shoulder; labral tear anterior, inferior, and posterior with a small ALPSA component

Treatment

Pan labral shoulder tears are often arthroscopically repaired. The arthroscopic approach to circumferential labral repairs utilizes percutaneous techniques to properly secure the labrum to the glenoid [3]. Tokish et al. [10] demonstrate arthroscopic repair of circumferential lesions of the glenoid labrum can restore stability of the glenohumeral joint and provide improvements in outcome measures.

Surgical Technique

After obtaining informed consent from the patient, a preoperative interscalene block is performed under ultrasound guidance, which is utilized in order to reduce the chance of nerve damage. The patient is then transferred to the operative room where a general anesthetic is administered via general endotracheal intubation. After the preoperative "time-out," the patient is placed in the beach chair position, and both of the patient's shoulders undergo range of motion and stability testing (anterior load-and-shift test, posterior push-pull test, and inferior sulcus sign) in order to document deficits in range of motion as well as anterior, posterior, and inferior instabilities. The shoulder is then draped and sterilized in the usual sterile orthopedic fashion.

The patient is positioned in the lateral decubitus position in order to provide the advantages of balanced suspension and lateral translation of the humerus [10]. All bony prominences are well padded. The posterior portal is established 2 cm inferiorly and even with the posterolateral corner of the acromion [10]. The arthroscopic sheath enters the glenohumeral joint by entering via the tip of the corocoid process.

An anterosuperior portal is established "outside-in" through the rotator interval. This portal is made 1 cm anterior and lateral to the anterolateral border of the acromion. A blunt switching stick is inserted and used as a guide for a 7.0 mm cannula (Arthrex, Naples, Florida). A midglenoid portal with an 8.25 mm cannula (Arthrex) is placed above the superior border of the subscapularis.

A 30° arthroscope is then inserted through the posterior portal followed by the anterosuperior portal in order to conduct a complete arthroscopy of the joint. The complete 15-point arthroscopy examines the biceps tendon and anchor, superior glenohumeral ligament, middle glenohumeral ligament, inferior glenohumeral ligament, rotator cuff, glenoid surface, humeral head, subscapularis, and capsule [3].

The posterior switching stick is then used as a guide to establish an additional 8.25 mm cannula (Arthrex) in the posterior portal. The posterior lesion is confirmed visually as circumferential separation between the glenoid and labrum. The posterior aspect of the circumferential lesions is approached first due to it being the least accessible [10]. However, the biceps anchor must be approached first in severe cases in order to reestablish a base of reference [10].

First, the glenoid and labrum must be prepared to ensure the labrum is properly mobilized from the glenoid. This is accomplished using a 15° elevator that is inserted into the midglenoid portal in order to gain direct access to the posteroinferior aspect of the labrum. Once the labrum has been mobilized, a bent rasp is put through the midglenoid portal to ensure there is an adequate bleeding surface of the glenoid. An arthroscopic biter is used to trim down the frayed and diseased portion of the labrum in order to expose the glenoid bone. Then, a 3.5-mm bone-cutting type resector blade is used via the midglenoid portal for debridement and preparation of the osseous glenoid. Proper osseous and soft-tissue preparation is essential to the healing of the capsulolabral structures [10]. The posterior half of the lesion, 6 o'clock to 12 o'clock position, is now prepared.

Placement of the posterior glenoid anchors is best facilitated through a modified posterolateral portal (7 o'clock) [10]. Placement of the posterior anchors through this posterolateral portal as opposed to the posterior portal prevents medial placement of the anchors and troughing of the cartilage during placement. A spinal needle is inserted 2–4 cm from the posterolateral aspect of the acromion, just inferior to the posterior portal. When the spinal needle is confirmed to be in the correct position, a small stab wound is made on the skin, and the needle is replaced by an anchor-inserter drill-sleeve with a sharp trocar. Several anchors may be placed through the posterolateral portal in a sequential fashion. A 3.0-mm SutureTak anchor guide (Arthrex) is placed on the peripheral aspect of the glenoid at the 7 o'clock position while the drill for the 3.0-mm SutureTak (Arthrex) is employed. Then, a 3.0-mm SutureTak (absorbable or polyethylethylketone [PEEK] or biocomposite) anchor with a number-2 FiberWire (Arthrex) is inserted through the same drill guide.

The suture anchor is confirmed to be secure by a brisk tug on the sutures. Suture passage is then ready to be completed. A suture shuttle device such as a SutureLasso (Arthrex) is inserted through the posterior portal while viewing through the anterosuperior portal. The shuttle device penetrates the capsule and emerges underneath the labrum on the face of the glenoid inferior to the anchor [10]. This approach allows reapproximation of the capsulolabral structures in an inferior-to-superior direction. Then a suture is shuttled out of the device and out of the shoulder through the midglenoid portal. One limb of the anchor is retrieved through this portal. This suture anchor limb is attached to the passing suture via a simple overhead knot. The unattached end of the passing suture is then pulled in order for the half hitch to pass retrograde through the labrum and out the posterior portal. The other limb of the suture anchor is also retrieved through the posterior portal. Next a sliding knot is tied and advanced to the glenoid labrum. This is backed up with three reverse half-hitches on alternating posts. The knot is cut just above the last half hitch by a knot-cutter. This process is then repeated along the length of the glenoid with anchors at the 7, 8, 9, and 11 o'clock positions.

The anterior labrum repair is completed similarly to the posterior repair, except that suture anchors are placed through the anteroinferior portal and do not require a separate stab incision [10]. The most inferior anchor in the glenoid is placed through the posterolateral portal in order to allow more direct drilling into the glenoid. Also, the 6 o'clock repair is performed via the direct posterior portal.

The axillary nerve is most at risk at the 5:30–6:30 position, approximately 12.5–15 mm inferiorly. Proper care must be taken to protect the axillary nerve while repairing the inferior portion of the glenoid capsular structures. To minimize risk of damaging the axillary nerve, the suture repair hooks should penetrate the capsule at a depth of 3–5 mm before turning the hook to exit under the glenoid labrum. The first anterior anchor is placed at the 5 o'clock positon. Subsequent anchors are placed at the 4, 3, and 2 o'clock positions. The arthroscope can either be in the anterosuperior portal or the posterior portal for the repair and shuttling of sutures.

The anterior labrum-bone junction should be prepared from the midglenoid portal. Similar suture passage and management techniques are employed with the goal being the reestablishment of the bumper and tension of the anterior capsulolabral structures.

Next the superior portion of the labrum (SLAP) is repaired using similar techniques. An 11 o'clock anchor, just posterior to the biceps anchor, can be placed through the anterosuperior portal. Most SLAP repairs consist of just one anchor at the posterior margin of the long head of the biceps tendon. Suture passage can be done in a similar fashion or passed directly with the use of a "bird beak" device (Arthrex) in order to eliminate a suture shuttling step [10]. The biceps tendon is ensured not to be strangulated, and proper preparation, labral reapproximation, and secure fixation are followed as they are throughout the procedure.

Circumferential labral repair is now complete. The shoulder is drained and all arthroscopes are removed. The wounds are closed and dressed sterilely. The anterior load-shift and posterior push-pull tests are conducted to ensure proper stability has been restored. A padded abduction sling is placed before the patient awakens from anesthesia. A cold therapy device is also applied on the operated shoulder.

The arthroscopic images below are from the same 18-year-old high-caliber football player who sustained a left shoulder labral tear while playing in a game. The patient had a history of recurrent instability and had experienced a recent event of anterior instability. He underwent left shoulder arthroscopic capsular labral repair (Fig. 17.3). This was a complicated case in which there was extensive labral tearing in the anterior, inferior, and posterior aspects necessitating additional expertise and a 6-anchor repair (Fig. 17.4). The patient had a significant scar tissue and a recent dislocation and prior scarring with ALPSA configuration (Fig. 17.5). This required extensive preparation and six total anchors in a 180-degree configuration for a posterior repair, inferior repair, and anterior repair requiring additional expertise in times due to this procedure (Figs. 17.6, 17.7 and 17.8).

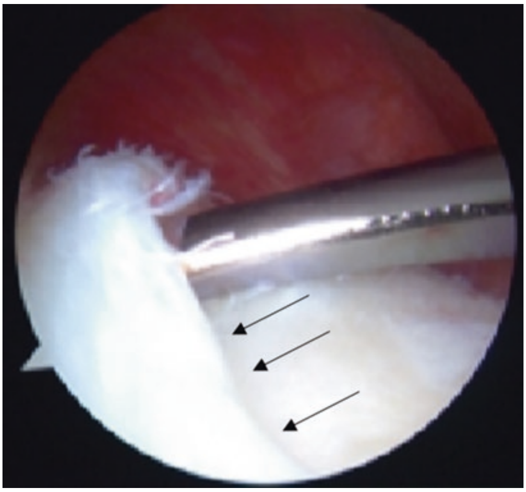

Fig. 17.3 Posterior labral tear

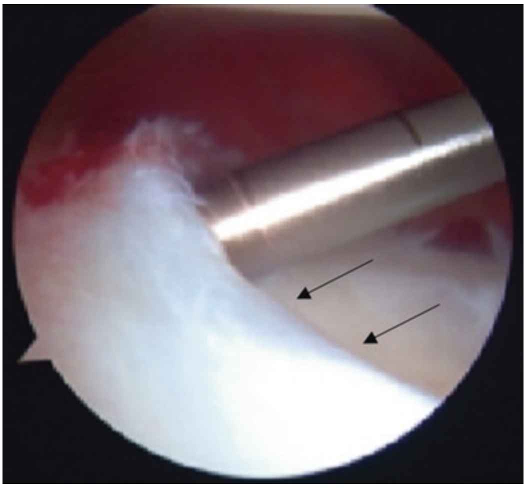

Fig. 17.4 Posterior labral tear; the instrument is inserted from the anterior portal to prepare the posterior labrum tear

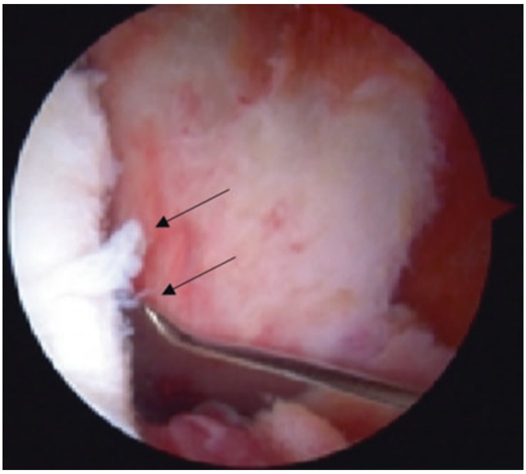

Fig. 17.5 Anterior labral tear with ALPSA configuration

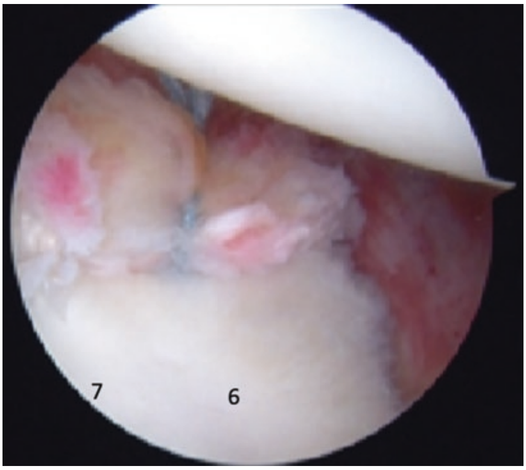

Fig. 17.6 6 and 7 o'clock anchors placed to repair the inferior portion of the tear

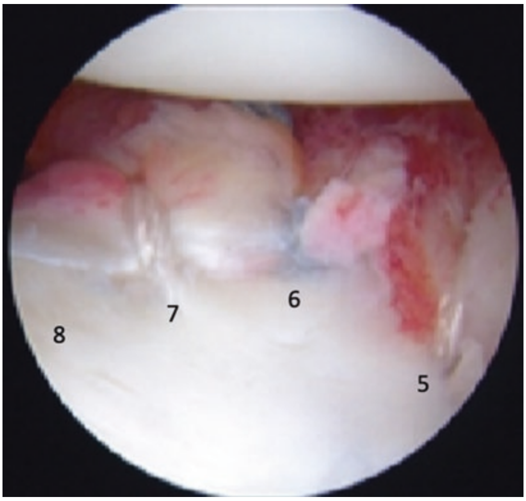

Fig. 17.7 Anchors placed to repair the extensive labral tear

Rehabilitation

Postoperatively, the patient is placed in an abducted sling for 6 weeks. Passive range of motion exercises are performed in shoulder abduction by a physical therapist at 3 weeks post-surgery [3]. Internal and external resistance exercises can begin at 6 weeks post-surgery [3]. Internal and external rotation exercises with the arm abducted can begin at 8 weeks post-surgery [3]. 12–16 weeks is focused on strengthening of the shoulder muscles with a return to sport activities at 6 months post-surgery [3].

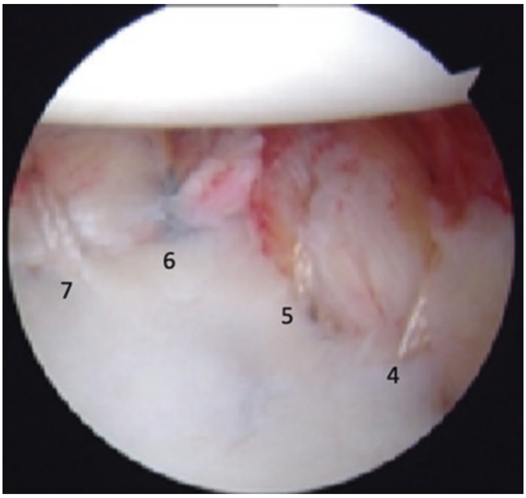

Fig. 17.8 The 6 o'clock anchor is the most inferior with 9 o'clock posterior and 3 o'clock anterior

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18

A 19-Year-Old Thrower with an In-Season Shoulder Injury

Michael C. Ciccotti and Michael G. Ciccotti

History

A 19-year-old, right-hand-dominant collegiate baseball pitcher presents mid-season to our clinic. He is accompanied by his father as well as a member of the college's athletic training staff. His primary complaint is right shoulder discomfort while throwing. He states that he felt mild to moderate pain while throwing "a few weeks into the season." At that time, he didn't feel that it was affecting his performance, and so he did not mention it to his teammates, trainers, or coaches. However, he states that the pain abruptly worsened several weeks ago, and now he experiences the symptoms regardless of pitch type and during every outing. Throughout the history, he refers to the effect on his performance in a number of different ways, commenting on decreased velocity and accuracy, stating that his "stuff" isn't the same and his pitches lack their normal movement. When asked to characterize the pain, he states that it is deep and posterior. When asked what phase of throwing it effects, he simulates two throwing motions and identifies the late cocking/early acceleration phases when his arm is abducted and maximally externally rotated. He denies any recent change in his mechanics. He has not added any new pitches to his repertoire. He doesn't believe his pitch counts are significantly different than the last season, but he does feel like he is being utilized more frequently. He notes that he frequently feels a clicking or popping sensation with overhead activities. He denies any significant sensation of instability associated with the discomfort. When asked, he denies any feeling of specific muscle weakness, numbness, tingling, cold intolerance, and neck pain. He denies symptoms with activities of daily living at this time.

He denies any current or previous treatments for his shoulder except the occasional over-the-counter nonsteroidal anti-inflammatory drugs (NSAID). He states he cannot recall any serious injuries he's sustained to his throwing arm in the past. He has never had any treatments for this arm.

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Physical Examination

He had no gross abnormalities of his gait or overall alignment. He demonstrated moderate corkscrewing but no gross imbalance on dynamic Trendelenburg testing [1–3]. His lower extremities demonstrated full, painless range of motion without abnormalities. He had no gross abnormalities on visual inspection but demonstrated some increased muscle bulk in the throwing shoulder. He had no scapulothoracic abnormalities. Systematic palpation was positive for posterior glenohumeral joint line tenderness, but negative for AC joint tenderness. Range of motion demonstrated 20° less internal rotation at 90° of abduction in the scapular plane in the throwing shoulder than the non-throwing shoulder. However, this was accompanied by increased external rotation such that total arc of motion was preserved. Muscle testing demonstrated 5/5 strength throughout with the exception of 4+/5 strength on empty can/supraspinatus testing with patient-reported discomfort. His supraspinatus weakness was resolved with the scapular retraction test [4].

Provocative testing demonstrated a positive Hawkins test with pain relieved by the scapular assistance test [3, 5]. He also demonstrated positive O'Brien's Active Compression and Modified Dynamic Labral Shear tests with pain unrelieved by the scapular retraction test [6, 7]. He had a negative Speed's, Yergason's, and Upper Cut tests for biceps pathology [7–9]. He had a negative crossover test [10]. His shoulder demonstrated normal stability with a negative apprehension/relocation test for anterior pain and negative sulcus sign [11, 12]. His neurologic and cervical spine exams were normal.

Imaging Studies

A standard series of plain radiographs including true AP of the glenohumeral joint in internal and external rotation, scapular Y, and axillary views of the involved right shoulder were unremarkable. MR arthrography of the right shoulder was obtained in order to optimize visualization of the labrum. Additionally, oblique axial and abduction external rotation (ABER) sequences were utilized to better visualize any involvement of the posterior labrum and/or adjacent posterosuperior rotator cuff, respectively [13–15]. Coronal views demonstrated detachment of the superior labrum at the bicipital root (Fig. 18.1); axial and oblique axial images identified extension of the labral tear into the posterosuperior quadrant (Fig. 18.2); and ABER views demonstrated increased signal at the posterior edge of the supraspinatus without evidence of significant tearing (Fig. 18.3). There was also some increased bony signal of the greater tuberosity consistent with internal impingement.

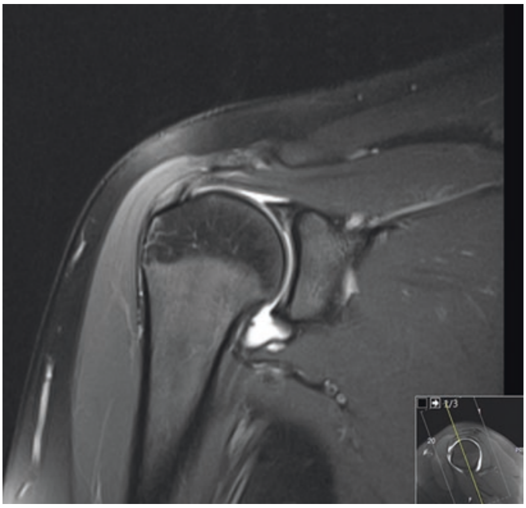

Fig. 18.1 Coronal MR image demonstrating superior labral tear

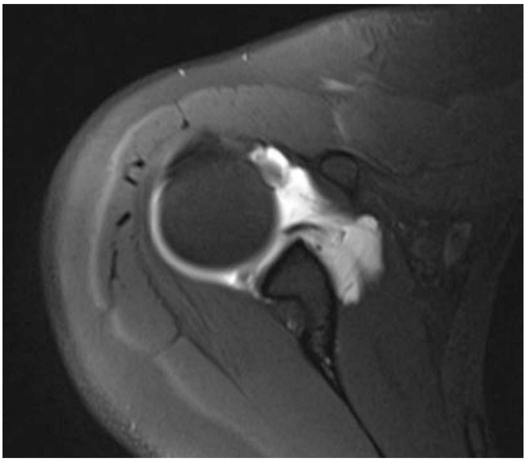

Fig. 18.2 Oblique axial MR image demonstrating tear extension into the posterosuperior labrum

Fig. 18.3 ABER MR image demonstrating increased signal in the posterosuperior rotator cuff with minimal tearing (Adapted by permission from Springer Nature, Spectrum of shoulder injuries in the baseball pitcher by Hugue Ouellette, John Labis, Miriam Bredella et al. (Jan 1, 2007))

Comprehensive Diagnosis

Our patient was diagnosed with a superior labrum anterior to posterior (SLAP) tear with extension into the posterosuperior labrum (from 12:00 to 9:00), associated mild posterosuperior rotator cuff partial thickness tearing, and mild to moderate kinetic chain deficits in the lower extremity and core. His history of mild but chronic symptoms culminating in an acute exacerbation of deep and posterior pain while in the late cocking/early acceleration phases of throwing is consistent with this diagnosis. His physical exam findings of positive O'Brien's Active Compression and Modified Dynamic Labral Shear tests coupled with normal biceps, rotator cuff, glenohumeral ligament, and acromioclavicular testing are consistent with this diagnosis as well. His imaging studies identify the anatomic lesions that would be consistent with these history and exam findings. Also of importance is the kinetic chain deficiency as noted on dynamic Trendelenburg testing.

Treatment Strategy

Our patient is a 19-year-old, right-hand-dominant collegiate pitcher in the middle of his sophomore season in whom we have diagnosed a SLAP tear with posterosuperior extension, mild posterosuperior rotator cuff partial thickness tearing, and associated kinetic chain deficits. Following a review of his history, examination, imaging findings, and diagnosis, we had a thorough discussion with the patient, his trainer, and his family regarding the full spectrum of both nonoperative and operative treatments. All the risks, benefits, and expectations of both treatments were outlined. In particular, the impact of each treatment on timing of return to play was discussed. Given his presentation during mid-season, both nonoperative and operative treatment would preclude return in the current season. Nonoperative treatment (requiring 3–6 months), if successful, would allow possible return for his junior season. Operative treatment (requiring 12–18 months) would disallow participation during both the current and upcoming season.

Nonoperative Treatment

Because our patient only had symptoms with throwing and none with activities of daily living or at rest, had not undergone any specific focused treatment to this point and had a mid-season presentation as discussed above, a nonoperative treatment program was agreed upon. An initial 3–6 week period of rest was begun with the intention of reassessment at repeated intervals to determine if he was ready to proceed to the next phase of rehabilitation. During that period of initial upper extremity/shoulder rest, supportive measures to control any initial inflammatory phase symptoms were initiated, including heat/ice contrast and a 14-day course of an oral nonsteroidal anti-inflammatory medication (as he had no medical contraindication). Our athlete did not have difficulty sleeping, and so an intra-articular corticosteroid injection was not provided. Biologic treatments such as platelet-rich plasma, stem cells, and various combinations of these modalities were discussed with him as well, but due to a lack of long-term, clinical evidence supporting their use, they were not utilized. During this initial rest phase, the patient begins to address range of motion with gentle passive, active-assisted, and active motion with the goal to normalize his glenohumeral and scapulothoracic motion [1]. In throwers, particular attention should be directed to the posterior soft tissues, which may be contracted and are often implicated in pathologic mechanism resulting in injury. In addition, while his shoulder was being rested from throwing, more aggressive rehabilitation of the remainder of the kinetic chain was initiated including core/trunk, lower extremity strength, and flexibility as well as aerobic conditioning.

At 2 weeks from initiating nonoperative treatment, his shoulder symptoms had resolved, and the intermediate phase was begun. Isotonic strengthening of the shoulder girdle and upper extremity was introduced while continuing to address the entirety of the kinetic chain. He did not experience any recurrent symptoms, and so the third phase of nonoperative treatment was begun. This focused on more aggressive strengthening of the shoulder girdle and upper extremity in order to enhance both power and endurance. Plyometrics and drills for proprioception, coordination, and neuromuscular control were also begun. At 5 weeks from beginning nonoperative treatment, he was pain-free with a normal exam including all provocative testing. At this point, an interval tossing/throwing program was initiated. The program began with gentle tossing at 30 feet, progressing to 180 feet on the flat ground. He remained asymptomatic and performed well thru this interval tossing. The intention was to then progress to throwing from a mound, first with fast balls at increasing effort/velocity and then off-speed pitches. Unfortunately, when he progressed to throwing from the mound with increasing effort, his presenting symptoms returned. On subsequent evaluation, his symptoms of deep and posterior pain were again present; his O'Brien's Active Compression and Modified Dynamic Labral Shear tests were again positive, while all other biceps, rotator cuff, glenohumeral ligament, and acromioclavicular testing was normal; his previously abnormal Dynamic Trendelenburg test findings had resolved. After discussion with the patient, the trainer, and his family, it was agreed upon that continued nonoperative treatment was unlikely to allow him to return to pitching, and so operative treatment was recommended.

Operative Treatment

The essential components of operative treatment for the symptomatic SLAP tear include (1) careful debridement of any nonviable, granulation tissue; (2) meticulous preparation of a biological, healing surface on the superior and posterior-superior glenoid rim; (3) firm attachment of the detached labrum to the adjacent glenoid rim; and (4) thorough treatment of any concomitant shoulder pathology [16]. Arthroscopic evaluation of our patient's shoulder revealed (1) a detached, unstable superior labrum with granulation tissue at the glenoid-labrum interface (Fig. 18.4); (2) peel-back of the labrum with abduction and external rotation of the arm (Fig. 18.5); (3) an extension of the tear into the posterosuperior

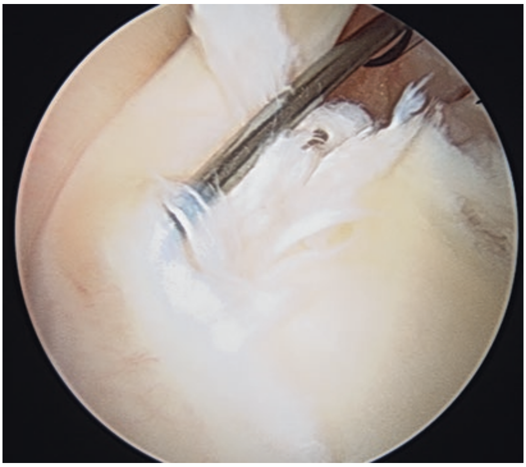

Fig. 18.4 Tear of the superior labrum with intact biceps tendon

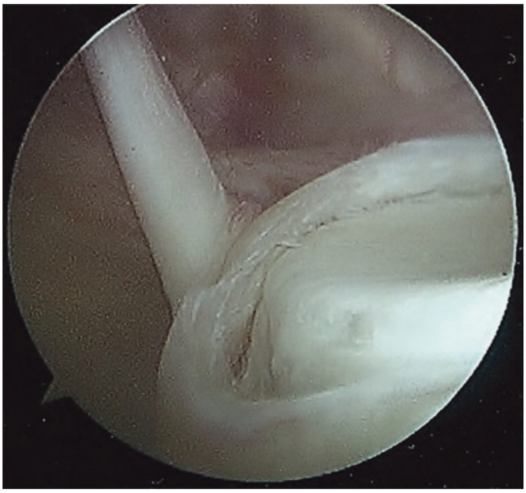

Fig. 18.5 Peel-back of the posterosuperior labrum with abduction and external rotation of the arm

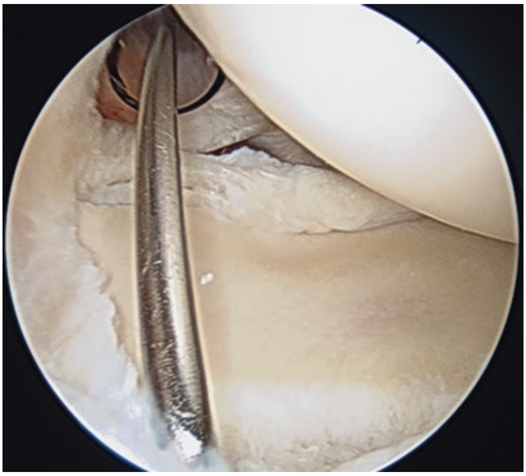

Fig. 18.6 Extension of the tear into the posterosuperior quadrant of the labrum

quadrant (Fig. 18.6); (4) minimal partial thickness (<20% of tendon depth) tearing of the posterosuperior rotator cuff (Fig. 18.7); (5) an intact biceps tendon with no evidence of pathology; (6) intact, stable anterior labrum and glenohumeral ligaments; (7) a normal subscapularis and rotator cuff interval; and (8) intact glenoid and humeral head articular cartilage.

Following diagnostic arthroscopy, the operative treatment included (1) debridement of the nonviable tissue underlying the superior and posterosuperior labrum using an arthroscopic shaver; (2) preparation of the adjacent glenoid rim with a combination of rasp, curette, and burr to provide a biologic surface for healing; (3) placement of simple knotless anchors posterior to the biceps anchor at 11:30, 10:30, and 9:30 (Fig. 18.8); and (4) gentle debridement of the posterosuperior rotator cuff partial thickness tearing to stable tissue.

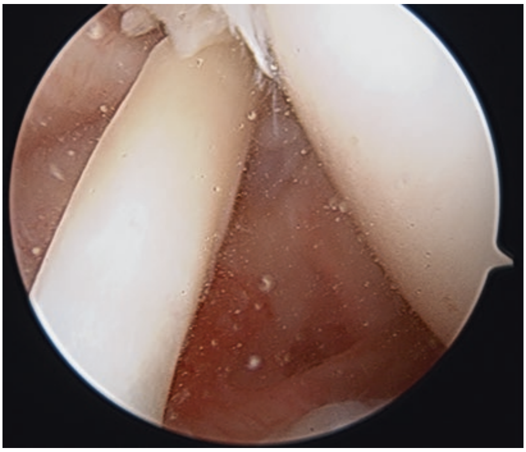

Fig. 18.7 Partial thickness tearing (<20% depth) of the posterosuperior rotator cuff

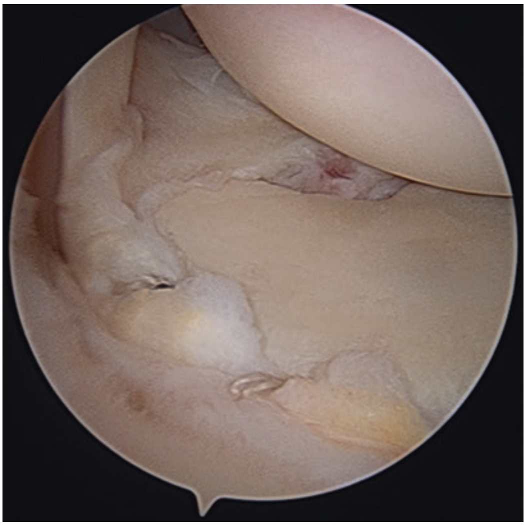

Fig. 18.8 Repair of the superior and posterosuperior labrum with three simple, knotless anchors posterior to the biceps root at 11:30, 10:30, and 9:30

Postoperative Rehabilitation

Postoperatively, the patient was immobilized in a sling/abduction pillow for 3 weeks. During this period of shoulder immobilization, the patient was allowed to actively range his hand, wrist, and elbow as well as to perform gentle pendulums [17]. At 2 weeks, gentle active-assisted range of motion was begun under the direct guidance of his athletic trainer. Gentle isometric shoulder strengthening was initiated at 4 weeks, and gentle resistance strengthening was started at 6 weeks postoperatively. Kinetic chain exercises for the legs, hips, and core as well as cardiovascular conditioning were performed throughout the postoperative period. Swinging a bat began at 3 months from surgery. He began a structured short toss/long toss program at 4 months after surgery. He remained pain-free with a normal exam, and so a mound program was initiated at 6 months postoperatively. His strength and endurance improved over the following 6 months during his off-season. He felt that he benefitted particularly from the increased focus on the kinetic chain and cardiovascular conditioning, which he admitted he sometimes neglected prior to his injury. At the beginning of his junior season, he was asymptomatic with a normal shoulder exam and no kinetic chain deficits. He was throwing bullpens and simulated games. He ultimately successfully returned to full competition with his the team by mid-season.

Summary/Conclusion

The management of SLAP tears in a mid-season, elite throwing athlete can pose a significant challenge for any clinician. Understanding the complex interplay of glenohumeral anatomy, the mechanics of the throwing motion, the adaptions necessary for stable shoulder function, and the mechanisms by which pathology may develop are essential. Although the precise etiology of SLAP lesions remains controversial, the proposed mechanisms highlight the adaptations acquired by throwers and the delicate balance required in order to prevent the development of pathology. Furthermore, this emphasizes the common coexistence of multiple potential sources of pathology as seen in our patient: a superior labral lesion with extension into the posterosuperior quadrant, internal impingement with inflammation of the posterior supraspinatus, and kinetic chain deficits.

Correct diagnosis requires an attentive history, a thorough physical examination of the shoulder and entire kinetic chain, and appropriate use of diagnostic imaging. These should all be concordant to arrive at the diagnosis of a SLAP lesion – a history including deep and posterior pain and clicking with overhead activity, expected examination findings of such provocative maneuvers as O'Brien's Active Compression and Modified Dynamic Labral Shear tests with no signs of biceps tendon injury, clear imaging with MR coronal, axial oblique, and ABER views confirming superior labral detachment.

Occurrence of the SLAP injury with respect to the time of playing season is an important factor to discuss with the athlete. In the majority of cases, management should begin with nonoperative treatment – including initial rest with focused rehabilitation of the involved shoulder, correction of all kinetic chain deficits, and then a progressive short toss/long toss/mound program [18, 19]. If the athlete has persistent or recurrent symptoms that prevent return to activities, then operative treatment is necessary. The operative treatment should include (1) debridement of all nonviable tissue underlying the superior and posterosuperior labrum; (2) preparation of the adjacent glenoid rim to provide a biologic surface for healing; (3) placement of secure, low-profile anchors for stable labral fixation; and (4) treatment of all concomitant pathology. A well-structured, precise rehabilitation protocol followed by a closely supervised tossing/mound program is essential for optimal outcome. Complications of operative treatment, including persistent discomfort, loosening of hardware, persistent rotator cuff defects at the transtendon portal sites, articular cartilage damage, post-traumatic arthritis, stiffness, persistent synovitis, and altered postoperative throwing mechanics must be reviewed with the patient [20–25]. Additionally, surgeons must consider the reported return to play rates following superior labral repair ranging from less than 50% to as high as 85% [20, 26]. Outcomes, however, in the overhead, throwing athlete with a mid-season SLAP tear, can be optimized if all the above principles are closely followed.

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19

Shoulder Pain in a Female College Swimmer

Scott Rodeo

History

The patient is a 20-year-old female college swimmer. She presents with shoulder pain in the middle of the collegiate swimming season in mid-January. She has had intermittent shoulder pain for the last several years, which typically occurs during heavy training in the early season. She now has recurrent shoulder pain that began following intense training during the holiday break at the end of December. At the time the team was doing increased "dry-land" training consisting of weight lifting and other resistance exercises with elastic tubing, in addition to two swimming workouts per day, 6 days per week. In the past the shoulder pain occurred only at the end of a workout and did not interfere with her ability to train, but the current pain has begun to interfere with her ability to train.

Her complaint at this time is pain localized anteriorly. She states that the pain is "around the biceps tendon." Pain occurs during the overhead recovery phase of the swimming stroke. Previously her pain would only begin at the end of her swimming workout, but now she has begun to have pain earlier in the workout. The pain then lasts into the evening following swim practice, with occasional night pain. She has an occasional sense that the shoulder "slips" but the primary complaint is pain rather than instability. She has no known history of instability episodes. She also reports infrequent paresthesias in the hand and fingers. The symptoms have begun to interfere with her ability to train.

Physical Examination

Visual inspection demonstrated a well-muscled female with the typical scapular protracted position that is often seen in swimmers. There were no signs of scapular dyskinesia. There were no deficits in shoulder strength or range of motion. There was tenderness to palpation anteriorly around the coracoid process and in the region of the bicipital groove. Pain was exacerbated with an active compression test (cross body adduction and internal rotation). Impingement signs including both Neer and Hawkins signs were positive. There was mild discomfort but not apprehension with the arm in abduction and external rotation. Laxity testing with load and shift demonstrated a

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moderate degree of anterior and posterior shoulder translation. There was a moderate (2+) sulcus sign. She had a similar degree of laxity in the contralateral (asymptomatic) shoulder. There were signs of generalized ligamentous laxity based on Beighton criteria (elbow and knee recurvatum, small finger hyperextension, trunk flexion, and the ability to oppose the thumb to the volar forearm) [1]. Wright and Adson tests for thoracic outlet syndrome were negative.

Imaging

Plain radiographs of the glenohumeral joint were normal. MRI scan is not typically ordered at the initial evaluation, unless there are physical examination findings or symptoms that would suggest frank rotator cuff tear, loose body, or displaced labral flap. In the typical swimmers shoulder, MRI is not likely to change the initial management. However, if the athlete fails to improve with appropriate physical therapy, MRI scan is typically ordered. If the patient is ultimately considered a surgical candidate, MRI scan is carried out to carefully assess the capsule, labrum, and rotator cuff.

Because this athlete had persistent and recurrent pain despite extensive physical therapy, MRI scan was eventually obtained. MRI scan demonstrated increased signal intensity in the supraspinatus tendon consistent with tendinosis (Fig. 19.1). There was thickening and increased signal intensity in the subacromial bursa. There was also thickening of the anterior shoulder capsule consistent with adaptive changes due to repetitive plastic deformation of the capsule due to shoulder translation (Fig. 19.2). The coracoid process had an elongated appearance, causing a narrow subcoracoid space and suggesting the possibility of subcoracoid impingement (Fig. 19.3).

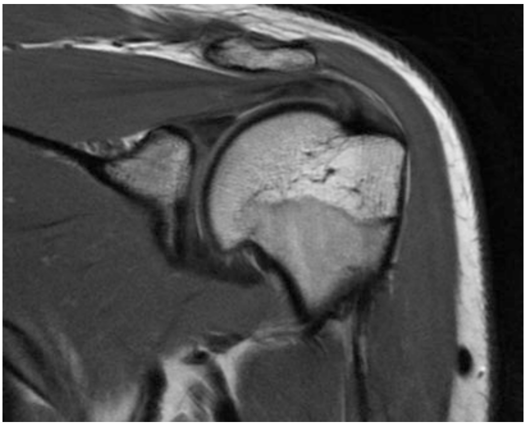

Fig. 19.1 MRI scan demonstrated increased signal intensity in the supraspinatus tendon consistent with tendinosis

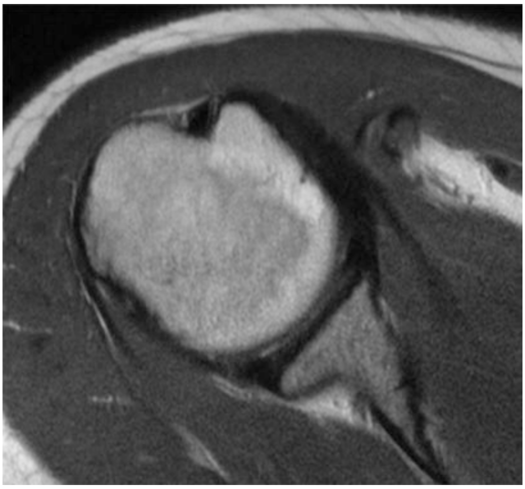

Fig. 19.2 The anterior shoulder capsule was thickened, consistent with adaptive changes due to repetitive plastic deformation of the capsule due to shoulder translation

Diagnosis

The working diagnosis is rotator cuff impingement in the setting of underlying shoulder laxity. Rotator cuff impingement occurs due to a combination of underlying shoulder laxity and loss of the dynamic stabilizing function of the rotator cuff muscles due to overuse and subsequent fatigue, leading to altered glenohumeral kinematics and resultant rotator cuff tendon and bursal impingement. Similar to other athletes performing repetitive overhead activities, many swimmers develop shoulder laxity. Such laxity is typically very well tolerated as long as the dynamic stabilizers (rotator cuff and periscapular muscles) function well. However, the high training demands can lead to muscle fatigue and subsequent loss of the humeral head-stabilizing

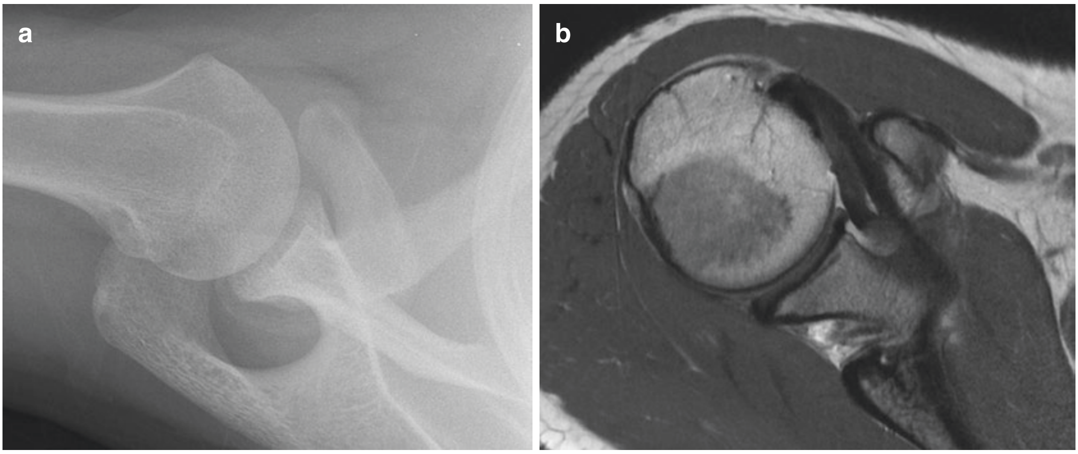

Fig. 19.3 (**a**) Axial radiograph demonstrating an elongated coracoid process. (**b**) Axial magnetic resonance image shows an elongated appearance of the coracoid, causing a narrow subcoracoid space and suggesting the possibility of subcoracoid impingement

effect of the rotator cuff. The altered shoulder kinematics then leads to superior migration of the humeral head and production of symptoms.

Initial Management

The initial management included modification in the dry-land and swimming training program. A short course of nonsteroidal anti-inflammatory medications can be helpful. A comprehensive physical therapy program focusing on rotator cuff, scapular muscle, and core muscle strengthening was initiated. Careful assessment for underlying muscle imbalances and/or strength deficits is important. For example, swimmers often display imbalances between the internal rotators and external rotators, as well as tightness in the anterior chest wall muscles including the pectoralis minor. An important aspect of the management is frequent communication between the physician, coach, athletic trainer, and athlete. Frequent reassessment of symptoms and response to treatment is important. Modifications in dry-land exercises and swimming training were made. For example, the use of hand paddles and pull buoys was decreased, as these lead to increased stress on the shoulders. More kicking sets were incorporated. A single subacromial steroid injection was used to manage pain.

The athlete was able to continue training at an adequate level that allowed her to continue to compete. She was able to complete the competitive swimming season. However, her performance was adversely impacted by the pain. Given the history of recurrent pain over several years, the recent increase in pain, the fact that the symptoms have begun to impact performance, and the failure to respond to a comprehensive non-operative management program, the option of surgical intervention was discussed.

Surgical Treatment

Surgery for recalcitrant shoulder pain in swimmers maybe a consideration if a comprehensive non-operative management program fails to improve symptoms and the athlete wishes to try to continue in the sport. Important factors to consider in the decision-making process include the athlete's short-term and long-term goals. It must be understood that return to full competition can take at least 6 months, and thus the athlete needs to consider timing relative to the competitive season. This often requires careful and honest assessment of goals, and is best guided by a careful discussion between the swimmer, important family members, and the coach.

As in any case, surgical management is guided by an accurate diagnosis based on symptoms, physical examination, imaging findings, and thorough arthroscopic inspection. Surgery for recalcitrant shoulder pain in swimmers typically involves shoulder stabilization by capsular plication, as there is usually some degree of underlying shoulder laxity that plays a role in persistent symptoms. Thickened and inflamed bursa is removed but formal acromioplasty is rarely required, as the pathology is non-outlet impingement. Labral pathology is also uncommon.

In this case the athlete had distinct pain localized to the region of the coracoid process. I have seen coracoid impingement in swimmers. The shoulder is repetitively brought into the position of forward flexion, adduction, and internal rotation during the swimming stroke, and this is a typical position causing coracoid impingement. Furthermore, anterior shoulder laxity may further contribute to impingement between the anterior shoulder capsule/subscapularis and the coracoid. Given the location of the patient's pain adjacent to the coracoid as well as the elongated appearance of the coracoid process on MRI scan, a diagnostic lidocaine injection was carried out under ultrasound guidance. This injection significantly improved the patient's pain, suggesting that coracoid impingement could play a role in her symptoms.

At the time of surgery a careful examination under anesthesia was done to determine the direction(s) and degree of laxity, followed by thorough arthroscopic evaluation. Examination under anesthesia demonstrated 2+ anterior translation, 2+ posterior translation, and 2+ sulcus sign. Arthroscopic inspection demonstrated the labrum to be intact with a positive "drive through" sign, indicative of a patulous capsule and shoulder laxity. The rotator cuff, subscapularis, and biceps were intact. Articular surfaces were normal. Inspection in the subacromial space demonstrated thickened and inflamed bursa but no bursal-sided rotator cuff pathology.

The procedure consisted of arthroscopic capsular plication, addressing both the anterior and posterior capsule (Fig. 19.4). Similar to management in other overhead athletes, only a modest capsular tightening was performed. Suture anchors were placed in the glenoid, and the sutures were then shuttled through the capsule/labrum. The arthroscope was then introduced into the subacromial space, and bursectomy was carried out. The coracoacromial ligament was then followed down to the coracoid process. An accessory anterior portal was used to resect the tip of the coracoid process in order to decompress the subcoracoid space, taking care to preserve the conjoined tendon attachment (Fig. 19.5).

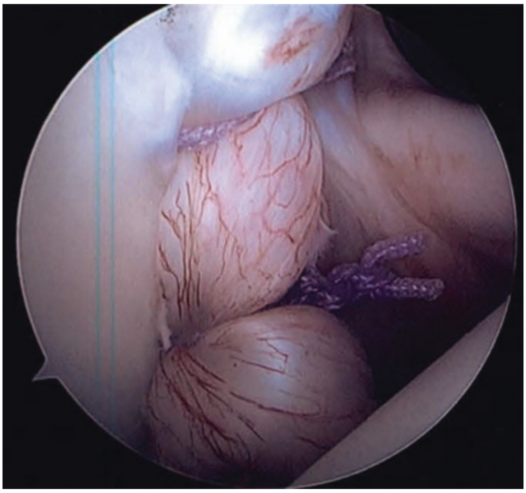

Fig. 19.4 Arthroscopic capsular plication was carried out, taking care not to overtighten the capsule

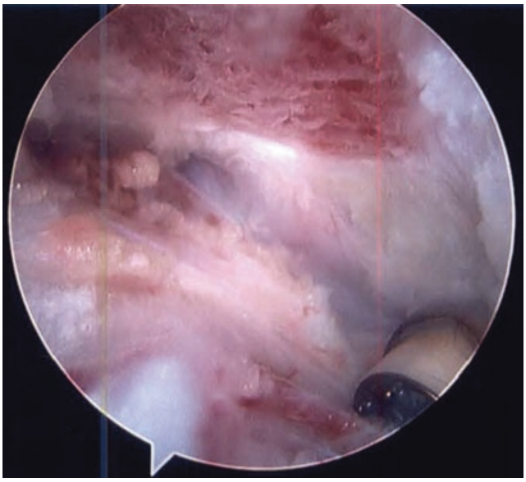

Fig. 19.5 Arthroscopic resection of the tip of the coracoid process was done to decompress the subcoracoid space, taking care to preserve the conjoined tendon attachment

Rehabilitation and Return to Sport

The initial postoperative rehabilitation protocol included protected range of motion to protect the healing shoulder capsule for the first 4 weeks. Isometric exercise for the rotator cuff, deltoid, and scapular muscles was initiated in the immediate postoperative period. Range of motion was progressed after the 4-week postoperative point, followed by a gradual strengthening program. Strengthening was initially began using surgical tubing, followed by progression to weight lifting exercises. Emphasis was placed on restoration of strength and muscle endurance in the subscapularis and serratus anterior muscles, as electromyographic studies have demonstrated that these muscles continually fire at a high rate during the swimming stroke and are thus susceptible to fatigue [2]. Core muscle strengthening was also emphasized.

The athlete was able to begin kicking sets in the water at weeks 6–8. This was done using a kickboard with the operated arm at the side, as well as kicking on her back. She began gentle sculling motions in the water at the 8-week postoperative point in order to start to reestablish her “feel” for the water.

Freestyle swimming was begun once there was full shoulder range of motion. This typically occurs after the 12-week postoperative point. Similar to other athletes returning to repetitive overhead activities, swimming training activities need to be progressed gradually, carefully monitoring symptoms. Open and frequent communication between the athlete, coach, trainer/physical therapist, and physician is critical to monitor and guide the return to training program.

Between months 3 and 6, the volume, frequency, and intensity of training were gradually progressed. Return to a full training schedule was possible at approximately 6–7 months from the time of surgery. The athlete was able to compete at her prior level the next competitive season, at 9–10 months following surgery.

Discussion and Conclusions

Shoulder pain is very common in swimmers due to the repetitive overhead motions. Surveys of national and elite-level swimmers demonstrate a high prevalence of shoulder pain. For example, a survey of elite Australian swimmers reported shoulder pain in 73/80 (91%) athletes [3], while a survey of the 2008 US Olympic swimming team found a history of shoulder pain in 29 of 42 (66%) athletes [4]. The position of the arm and shoulder when the hand enters the water during freestyle and butterfly swimming is forward flexion, adduction, and internal rotation, which is a typical impingement position. Such repetitive impingement can lead to cumulative microdamage to the tendon, resulting in tendinosis. In addition to such extrinsic/outlet impingement, intrinsic tendon injury from repetitive strain may contribute to development of tendinosis. MRI scan of shoulders in swimmers often demonstrates alterations in signal and morphology in the rotator cuff tendons consistent with underlying tendinosis [3]. The relationship between morphological changes in the tendon (tendinosis) and symptoms is poorly understood.

One of the most important factors to recognize and address in the evaluation and management of shoulder pain in swimmers is the role of overuse, leading to muscle fatigue and subsequent alterations in shoulder kinematics. This is the rationale for the critically important role of a comprehensive strengthening program. The athlete should also be carefully examined for any evidence of scapular dyskinesis. Scapular muscle fatigue is common in swimmers due to the repetitive overhead activity, and this can result in scapular dyskinesis. Careful physical examination of scapular position, motion, and kinematics is important to detect scapular dyskinesis. Training and rehabilitation programs that focus on establishing strength, endurance, and improved function of the periscapular muscles are critical.

We carried out a clinical and ultrasonographic analysis of the 2008 US Olympic swimming team to assess training history, injury history, prevalence of shoulder pain, and shoulder function [4]. Each athlete also underwent a comprehensive physical examination of both shoulders followed by ultrasound with dynamic images to assess for subcoracoid impingement and subacromial impingement. We found a high prevalence of rotator cuff and biceps tendinopathy, which was associated with increased symptoms. A history of shoulder pain was reported by 29 of 42 (66%) athletes. Morphological changes consistent with tendinosis were common in the supraspinatus/infraspinatus (44/46 shoulders; 96%) and biceps (33/46 shoulders; 72%). Subacromial impingement was seen in 34 of 41 shoulders (83%), and subcoracoid impingement was seen in 17 of 46 shoulders (37%). There was an increased odds ratio for rotator cuff tendinosis in swimmers who reported worse scores for pain with activities (OR, 0.10; 95% CI, 0.01–0.78; $P = 0.028$) and in those with a positive sulcus sign (OR, 33.2; 95% CI, 3.09–355; $P = 0.004$). There was also an increased odds ratio for impingement in swimmers with a positive sulcus sign (OR, 5.40; 95% CI, 0.80–36.3; $P = 0.083$), suggesting a role for shoulder laxity.

The role of tendinopathy is further supported by a survey of elite Australian swimmers, where 90% had a positive impingement sign and 69% (36/52) of those examined with MRI had supraspinatus tendinopathy [3]. Furthermore, there was a strong correlation between the presence of an impingement sign and MRI-determined supraspinatus tendinopathy ($r^2 = 0.49$, $p < 0.00001$). The number of hours swum/week ($r^2 = 0.39$, $p < 0.005$) and weekly mileage ($r^2 = 0.34$, $p = 0.01$) both correlated significantly with supraspinatus tendinopathy.

There is frequently some degree of capsular laxity in athletes engaging in such repetitive overhead activities. Such laxity may be very well tolerated as long as there is good muscle strength. However, with rotator cuff tendon fatigue due to repetitive loading, the dynamic stabilizers may be compromised, leading to alteration in shoulder kinematics and resultant shoulder impingement and symptom production. Making the distinction between laxity (an individual's normal function) and instability (suggesting pathology) can be challenging, as many swimmers have a degree of capsular laxity which is simply their underlying anatomy and there is often a similar degree of laxity in the contralateral, asymptomatic shoulder. This can it make difficult to determine how much the laxity contributes to symptoms. Similar to other overhead athletes, some degree of laxity is very common and is even necessary for performance of the sport. Given these considerations, only a modest capsular plication is carried out when surgery is undertaken.

In addition to pain related to the rotator cuff due to tendinopathy, bursitis, alterations in shoulder kinematics, laxity, and impingement as described above, there are other considerations in the differential diagnosis. These include coracoid impingement, labral tears, os acromiale, rotator cuff tears in older (masters) swimmers, biceps pathology, and thoracic outlet syndrome. All of these entities should be considered when evaluating shoulder pain in a swimmer.

A critically important part of the discussion regarding surgical management is providing realistic expectations for the swimmer. Similar to other activities with repetitive overhead motions (throwing, tennis), not all athletes can return to same level of training or competition. It should be understood that some level of residual shoulder discomfort during swimming may persist following surgery, which is understandable and even expected given the high prevalence of shoulder pain in high-level swimmers.

There are few reports in the literature on the outcomes and rate of return to competitive swimming following shoulder surgery. One of the earliest reports on the outcome of anterior acromioplasty in overhead athletes included seven swimmers and reported one good, four fair, and two poor results [5]. Brushøj and coauthors reported on 18 competitive swimmers who underwent shoulder arthroscopy for shoulder pain that failed to resolve with physical therapy [6]. These authors reported that the most common findings at surgery were labral pathology in 11 (61%) and subacromial impingement in 5 shoulders (28%). The operative procedures included labral debridement in 11 swimmers, coracoacromial ligament release in 4, and subacromial bursectomy in 4. Nine out of 16 swimmers (56%) were able to compete at pre-injury level. The authors concluded that arthroscopic debridement of labral tears or bursectomy in swimmers with shoulder pain has a low success rate with regard to return to sport, suggesting that improved understanding of shoulder pain in swimmers is needed. These earlier studies that included only subacromial decompression and labral debridement suggest that underlying instability may not have been recognized, contributing to the low rate of return to sport.

We reported on the results of arthroscopic capsular plication in 15 competitive swimmers (18 shoulders) who had failed extensive conservative management [7]. All patients demonstrated laxity at the time of examination under anesthesia. Patients were contacted at an average follow-up of 29 months (range, 8–42), and a swimming history, American Shoulder and Elbow (ASES) scores, and L'Insalata scores were obtained. Eighty percent (12/15) of patients returned to competitive swimming although only 20% (3/15) were able to return to their pre-injury training regimen volume. All patients subjectively reported improved pain after surgery based on ASES score and L'Insalata score. Although our results demonstrate that arthroscopic capsular plication has utility in the treatment of shoulder pain in swimmers who have failed non-operative treatment, the inability of some athletes to return to pre-injury training volume illustrates the difficult nature of shoulder pain in swimmers.

In conclusion, management of shoulder pain in swimmers can be a difficult management problem. The mainstay of treatment is a comprehensive rehabilitation program. Similar to other overhead athletes, swimmers often acquire some degree of shoulder laxity due to the repetitive overhead motions. Laxity can be very well tolerated with rotator cuff and scapular muscle strengthening. However, overuse due to the excessive demands of swimming training can result in rotator cuff muscle fatigue and subsequent dysfunction, leading to altered shoulder kinematics and onset of shoulder pain. This is the rationale for modest capsular plication in swimmers who fail to improve with extensive rehabilitation. However, it is recognized that not all swimmers are able to return to high-level competitive swimming once they reach the point of requiring surgery. It is likely that intrinsic changes in microstructure and composition of the rotator cuff and biceps (tendinosis) may also contribute to pain, and further research is required to identify methods to treat painful tendinopathy.

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Elbow Pain in a Throwing Athlete

20

James B. Carr II and Joshua S. Dines

History

A 20-year-old, right-hand dominant college baseball pitcher presented with a 2-month history of right medial-sided elbow pain while throwing. He began having soreness in the elbow during fall season workouts. He denied any previous traumatic events but reported that his pain became acutely worse while pitching in a scrimmage 1 week ago. The pain prevented him from completing his outing, and he was unable to return to throwing since that time. He reported decreased velocity over the last month, and he also required more time to fully warm up. He denied any numbness, tingling, or weakness in the hand or fingers. He also denied any mechanical symptoms, such as catching, locking, or clicking in the elbow.

The pain was only aggravated with throwing and did not affect his activities of daily living. Prior to presentation he attempted a trial of nonsteroidal anti-inflammatory (NSAID) medications along with activity modification, which were not helpful in relieving his symptoms. He specifically denied any previous history of significant medial-sided elbow pain. He had no other injuries to report at the time of presentation.

Physical Examination

The physical examination of a throwing athlete with medial-sided elbow pain should begin with the cervical spine to rule out a neurologic etiology. The examiner should then progress along the upper extremity with a careful examination of the shoulder and elbow while also noting the distal neurovascular exam of the extremity. The contralateral upper extremity should also be examined to note any contralateral differences.

It is also important to examine the patient's core, hips, and pelvis to localize any pathology along the thrower's kinetic chain, which may affect power, endurance, or throwing mechanics.

The physical examination for the presented athlete was the following:

Cervical Spine Exam

- Overall cervical spine alignment was normal.
- The patient demonstrated full cervical spine range of motion (ROM) in flexion, extension, rotation, and lateral bend without any pain.
- Provocative tests were unremarkable.

Shoulder Exam

- No obvious muscle atrophy was present.
- Scapular motion was smooth with no signs of dyskinesia during forward elevation and abduction.
- The patient had excellent ROM on the unaffected left shoulder. The right shoulder

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demonstrated 10° less forward elevation than the left side.
- The right shoulder had 20° less internal rotation compared to the contralateral side.
- With the arm abducted to 90°, the right shoulder had 105° of external rotation.
- Specific tests for labrum pathology, biceps tendinitis, and rotator cuff impingement were negative bilaterally.
- Rotator cuff strength was 5/5 bilaterally.

Elbow Exam

- The right elbow was lacking 5° of extension with a full flexion arc to 140°. There was no loss of extension in the left elbow.
- The patient reported tenderness with palpation along the UCL with increased tenderness proximally near the medial epicondyle at the UCL origin.
- No pain was elicited with resisted wrist flexion or forearm pronation.
- Tinel's test was negative along the cubital tunnel.
- The elbow was stable to varus and valgus stress, but there was pain with valgus stress.
- Moving valgus stress test was positive.
- He had pain with the milking maneuver test localized to the UCL.
- There was no pain with forced hyperextension.

Distal Neurovascular Exam

- There was full sensation and strength in the median, ulnar, and radial nerve distributions of the hand.
- The patient had strong, symmetric radial pulses.

Core/Hip/Pelvis Exam

- The patient had normal posture with appropriate core strength and flexibility during rotation and lateral bending.
- No areas of tenderness were found along the pelvis or hips.
- The patient had fluid hip ROM bilaterally.
- There was full strength and sensation to each distal lower extremity.

Comprehensive Differential Diagnosis

When developing a differential diagnosis for medial-sided elbow pain, the physician must initially determine whether the pain is coming from the elbow or from another location. The vast majority of throwing athletes who present with medial-sided elbow pain will have pathology localized to the elbow joint or to the nearby surrounding structures. However, less common etiologies, such as cervical radiculopathy, should be considered initially and can be subsequently ruled out with a normal neurologic history and examination. Neck pain, radiating radicular pain, and numbness and tingling should raise the suspicion for possible cervical spine pathology.

Once the examiner has located the athlete's etiology of pain to the elbow, the following conditions should be included in the differential diagnosis list:

- Ulnar collateral ligament (UCL) sprain/tear
- Flexor-pronator tendinitis
- Ulnar neuritis
- Olecranon or sublime tubercle stress fracture
- Valgus extension overload
- Medial epicondyle apophysitis
- Medial epicondyle fracture

Ruling out various pathologies is accomplished with a thorough history and physical examination, along with imaging when indicated (see below). It is also possible to have multiple etiologies for pain, such as ulnar neuritis and a UCL tear, so the physician should remain open-minded to concomitant pathology when making a diagnosis.

A UCL sprain or tear is arguably the most feared diagnosis for a competitive thrower. It is less likely present when there is no tenderness along the UCL and when the patient has no pain with static valgus stress or moving valgus stress test. Flexor-pronator tendinitis may be confused for a UCL sprain or rupture due to its similar location of pain. The presence of pain with resisted wrist flexion and forearm pronation can help the physician make the diagnosis of tendinitis. Additionally, the pain of flexor-pronator tendinitis is typically located directly over the medial epicondyle, although some patients also report pain extending along the proximal pronator-flexor muscle wad.

Ulnar neuritis involves pain along the cubital tunnel, which will be more posterior than pain of flexor-pronator tendinitis or a UCL tear. Depending on the degree of symptoms, patients may also have associated numbness and tingling extending distally to the small and ring fingers. Patients with ulnar neuritis often have a positive Tinel's test along the cubital tunnel as well.

A patient with an olecranon stress fracture will have pain directly over the olecranon border or the posteromedial tip of the olecranon. The patient may also report pain with any activity that activates the triceps muscles in addition to pain with throwing. A stress fracture can also be present with valgus extension overload (VEO), which is a constellation of symptoms and pathology associated with the repetitive high stress generated in the elbow of a throwing athlete. Other common findings associated with VEO are posteromedial olecranon osteophytes, osteochondritis dissecans of the capitellum, and loose bodies within the elbow joint. These latter diagnoses will often present with mechanical symptoms and may also include lateral elbow pain. VEO is often associated with UCL insufficiency, so physicians should always consider this when a sign or symptom of VEO is present.

Medial epicondyle apophysitis is an overuse injury that occurs in skeletally immature throwing athletes. It should be suspected in pediatric and adolescent patients with a history of excessive throwing patterns and insidious onset of medial-sided elbow pain. In contrast, when a skeletally immature patient reports acute onset of medial elbow pain that can be localized to a single throw, a medial epicondyle fracture is more likely. Of note, the medial epicondyle is the last ossification center about the elbow to fuse, typically between 16 and 18 years of age. Therefore, any throwing athlete 18 years old or younger should be considered a skeletally immature patient at risk for physeal injury.

Imaging

Radiographs of the affected elbow should be the initial imaging study of choice. We typically obtain these radiographs at initial presentation to investigate for pathology and aid in diagnosis. Radiographs are preferred initially because they are relatively less expensive, are able to be obtained in most ambulatory clinic settings, and can quickly provide valuable diagnostic information. At minimum, an anteroposterior and true lateral of the elbow should be obtained. External and internal oblique views can also be obtained to better visualize the humeral lateral and medial columns, respectively. Initial radiographs are often unremarkable, though certain features may be routinely seen depending on the patient age, diagnosis, and chronicity of symptoms. Common radiographic findings in patients with medial elbow pain include fracture, physeal widening or fragmentation, calcification within the UCL, a hypertrophic sublime tubercle, posteromedial olecranon osteophytes, and loose bodies within the elbow joint.

After radiographic evaluation, we prefer noncontrast magnetic resonance imaging (MRI) of the elbow as the first advanced imaging study of choice. An MRI should be obtained when a diagnosis has not been established in the setting of normal radiographs or if further characterization of a radiographic finding is desired. Specifically, an MRI should be ordered to further evaluate suspicion for a UCL sprain or tear, OCD lesion, suspected stress fracture in the setting of normal radiographs, or unremitting flexor-pronator tendinitis.

In regard to UCL sprain/tear, the use of dynamic ultrasound has been proposed as a less expensive, quicker modality for diagnosis [1, 2]. While these are advantages of ultrasound, we still prefer MRI for a patient with a suspected UCL tear for a few reasons. First, ultrasound is user dependent and may incur greater variability than

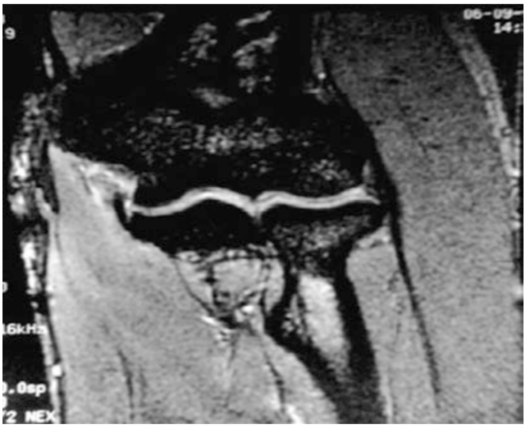

Fig. 20.1 MRI was ordered, which revealed a full-thickness tear off the medial epicondyle of the anterior bundle of the UCL

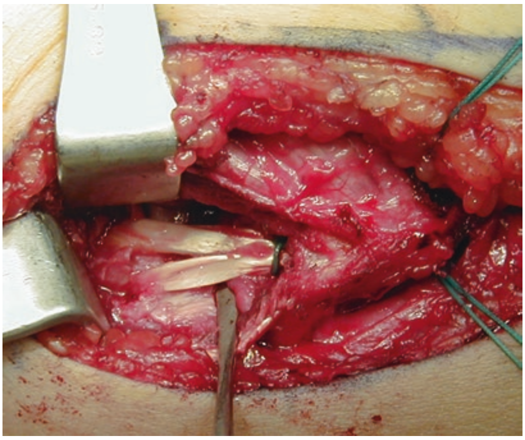

Fig. 20.2 Example of anatomic reconstruction for reestablishing the integrity of the UCL

MRI. Second, MRI allows for full assessment of the elbow joint and surrounding structures, which helps the physician diagnose and treat any additional pathology. Lastly, robust studies to prove that dynamic ultrasound is superior, or even comparable, to MRI in diagnosing a UCL sprain or tear are currently lacking.

Findings in Current Case

The currently discussed patient had unremarkable elbow radiographs. Due to the high suspicion for a UCL sprain or tear, an MRI was ordered, which revealed a full-thickness tear off the medial epicondyle of the anterior bundle of the UCL (Fig. 20.1).

Treatment Options and Results

The gold standard for a complete UCL tear is anatomic reconstruction, as this provides the player with the best chance of returning to competitive throwing (Fig. 20.2). Unlike certain partial injuries, a full-thickness tear is significantly less likely to heal adequately without surgical intervention. Several reconstruction techniques have been described with successful return to play rates in greater than 85% of pitchers [3–8]. The two most common techniques are the "figure of 8" graft placement first described by Jobe [9] and later modified by Azar [10] and the use of humeral suture tunnels described in the docking technique [11]. Regardless of the chosen surgical approach, the goal of the surgery is to restore the native anatomy and strength of the UCL while minimizing complications in order to give the athlete the best chance to return to competitive throwing. Surgeons should perform the technique with which they are the most comfortable.

While both techniques have demonstrated success in the elite-level pitcher, we prefer the docking technique for several reasons. First, it requires less bone removal from the humerus, which imparts less theoretical risk of medial epicondyle fracture. The docking sutures are tied over a humeral bone bridge, which further protects the tunnels from excessive force. Second, this construct allows for easier, more reproducible tensioning of the graft. Third, as described, the technique utilizes a flexor-pronator muscle split as opposed to elevating the muscle, which results in a less risk to the ulnar nerve. Lastly, and arguably most importantly, the docking technique has resulted in superior return to play rates compared to the modified Jobe technique (90–97% vs 77–93%, respectively) [4, 5, 12]. Furthermore, the docking technique has demonstrated a lower overall complication rate (19.1% vs 6%), especially in regard to postoperative ulnar neuropathy (9% vs 4%) [12, 13].

The most commonly used graft for the reconstructed UCL is the palmaris longus tendon. This tendon is ideal because it is appropriately sized to fit through the ulnar and humeral tunnels while also being large enough to withstand the valgus forces of the throwing motion. There is also minimal morbidity to the patient from palmaris harvest. Of note, epidemiologic studies have revealed that the palmaris longus tendon will be absent on one side in 16% of patients and on both sides in 9% of patients [14]. Therefore, when the decision is made to proceed with UCL reconstruction, the physician should examine the patient to ensure that it is present. We prefer to use the ipsilateral palmaris longus tendon since it is easy to obtain within the planned surgical field and allows the surgery to affect only one limb. In the case of absent ipsilateral palmaris tendons, we prefer gracilis autograft from the contralateral leg. The contralateral leg is used because this is the athlete's landing leg during the throwing motion. Sparing the push-off leg is thought to be preferable because a thrower uses this set of hamstring muscles more than the hamstring muscles of the landing side [15, 16]. If there is any doubt about the presence or size of the patient's palmaris tendon, then the surgeon should prep and drape the contralateral leg into the sterile field and be prepared for gracilis autograft harvest if necessary. Good short- and long-term results have been reported with both autograft types [5, 7, 17, 18].

Recently, a new technique referred to as "internal bracing" has been proposed as a viable surgical alternative for patients with a partial UCL tear who fail conservative management or desire surgery [19, 20]. In this technique, a partial tear is primarily repaired and then augmented with a suture anchor construct with collagen tape, which forms an internal brace along the repair [19] (Fig. 20.3). This construct may be particularly advantageous in patients with an avulsion-type, partial UCL tear. Proposed advantages of this technique include bone preservation and a potentially faster return to play compared to reconstruction. Classically, UCL repair leads to inferior results compared to reconstruction, but these reports were prior to the introduction of the internal brace [10, 21–23]. Initial biomechanical cadaveric studies have supported excellent strength of repair using the internal brace, but current in vivo data and long-term follow-up results are lacking [20].

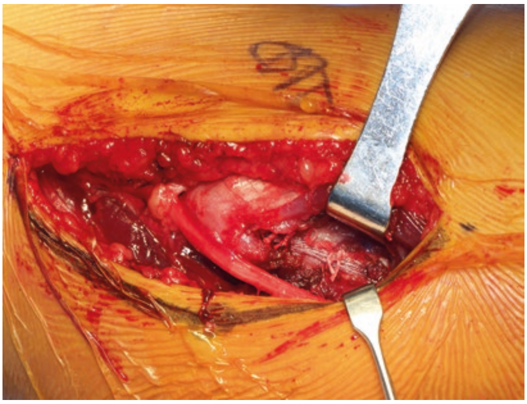

Fig. 20.3 Example of "internal bracing," i.e., repair of a partial tear with augmentation with a suture anchor construct and collagen tape

Following UCL reconstruction, the patient must undergo an arduous rehabilitative process. While the exact details of a preferred postoperative rehabilitative plan may differ between surgeons, most protocols involve four phases over the course of 12–15 months [24].

The first phase is focused on regaining full elbow motion, especially extension, along with reducing pain and inflammation. Strengthening exercises are minimal during this phase and mainly involve submaximal isometrics for the elbow flexor, elbow extensor, wrist flexor, wrist extensor, supinator, and pronator muscle groups. Scapular activation and strengthening are also initiated in this phase. The second phase begins when the patient exhibits full range of motion with minimal pain. The main goal of this phase is reestablishing muscle endurance and strength along with neuromuscular control of the upper extremity. Exercises are progressed along a structured strengthening program, such as the established Thrower's Ten Program [25]. Regaining shoulder range of motion, especially internal and external rotation at 90°, is important during this phase to help reduce stress on the UCL graft during future throwing exercises. Phase 3 transitions the athlete to more rigorous strengthening exercises in anticipation to a return to throwing. Finally, in phase 4 the athlete resumes throwing activities during an interval throwing program that builds up to long toss and eventually a return to pitching.

Return to play can be quite variable and depends on the previous level of competition, time of the year, and desire to return to competitive throwing. Every patient is unique in their ability to heal and recover the previous level of function, and protocols should be tailored accordingly. Therefore, the rehabilitative timeline should be flexible and allow an athlete more time to return if needed. Advancement through the postsurgical rehabilitative process is contingent on the ability to successfully complete a step without adverse symptoms. Full return to play is variable with most studies reporting an average of 11–12 months [3, 5, 7, 18, 26, 27], though it is not uncommon for higher-level athletes to require more time until they are ready to return without restrictions.

While anatomic reconstruction is the gold standard for a complete UCL tear, a partial tear can often be treated successfully without surgery in the appropriate setting [28–32]. The management of a partial UCL tear in a throwing athlete is influenced by many factors, including the grade of the partial tear, location of the tear, baseball position of the player, degree of symptoms, patient preference, and desired timeline for return to play. Treatment options generally include either conservative management, which includes physical therapy followed by a graduated throwing program, or surgical treatment, which entails anatomic reconstruction of the UCL or internal bracing depending on intraoperative findings. The use of biologic injections, most notably platelet-rich plasma (PRP) and stem cells, has also gained attention as a possible adjunct to conservative management.

Recently, biologic injections, especially PRP and stem cells, have gained popularity as an adjunct for conservative treatment of partial UCL tears. It is reasonable to consider PRP injections for a partial UCL tear, especially in the high-level athlete, though treating physicians should be knowledgeable of the potential risks and benefits of such modalities. A few studies have reported encouraging results following PRP injection in the setting of a partial UCL tear [29, 30, 33]. However, the amount of research on this topic is still limited, and no study to date has shown a faster return to play rate with the use of PRP injections. Furthermore, these results can be difficult to interpret due to the wide variation in PRP composition, location of injections, timing of injections, and amount of injections. While initial results are promising, additional studies are needed to further elucidate indications for PRP injections in the management of partial UCL tears.

Regardless of the chosen conservative plan, progression along the rehab program is always contingent on the ability to advance without any adverse symptoms or setbacks. The patient should undergo an initial period of rest for 1–2 weeks until all pain has resolved. Once this is accomplished, physical therapy may begin with the goal of returning to a graduated throwing program at 4–6 weeks. While each patient is unique, most studies cite an average of 12 weeks until full return to competitive throwing after conservative management of a partial UCL tear [28–30, 33].

Overall, return to play rates following conservative management of a partial UCL tear are favorable and largely dependent on the grade of the tear. Patients with a grade I tear have been reported to successfully return to play with rates up to 100% following conservative management [28]. Return to play following conservative management after a grade II partial UCL tear is less predictable, yet still favorable, with a return to play rate reported between 66% and 94% [28–30]. As previously noted, initial studies indicate that conservative management is notably less successful for patients with a distal partial UCL tear, and these patients should be counseled accordingly.

How this Patient Was Treated

After a conversation with the current patient, he elected to proceed with UCL reconstruction using his ipsilateral palmaris longus tendon. He successfully underwent the surgery and was able to complete the postoperative rehabilitative protocol without any major setbacks or complications. He returned to competitive throwing at the collegiate level 12 months after his surgery.

Summary of Conclusions

Medial elbow pain in throwing athletes can be debilitating. While the elbow UCL is the most common cause of the pain, it is important for treating physicians to have a good understanding of the extensive differential diagnosis of medial elbow pain in throwing athletes. Full-thickness tear in athletes wanting to continue playing baseball typically requires reconstruction. Multiple techniques for ligament reconstruction have been described, and while surgeons should use the technique that they are most comfortable with, we prefer the docking technique based on its superior outcomes in systematic reviews. In general, results are very good, but a successful outcome depends on a long postoperative rehabilitation process. Partial tears can often be managed conservatively with a structured physical therapy program and gradual return to an interval throwing program. Some recent studies have highlighted the potential benefits of biologic injections to augment conservative management. Further research regarding biologics may improve the outcomes of non-operative management.

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21

Recurrent Anterior Glenohumeral Instability in an In-Season Athlete

Brandon J. Erickson, Ryan A. Mlynarek,
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History

The patient is a 21-year-old college junior at a Division I school who is a starting X wide receiver on the football team. He has aspirations of playing professionally in the national football league (NFL) and has been named to the Biletnikoff watch list during the preseason. He is right-hand dominant and has a history of an acute, traumatic anterior dislocation of his right shoulder at the end of last season. It was a contact injury and required a formal reduction. Magnetic resonance images (MRI) at that time demonstrated a soft tissue Bankart lesion with no appreciable glenoid bone loss (Fig. 21.1a–c). Given his age and activity level, he underwent an arthroscopic anteroinferior labral stabilization at the end of his season in December (Fig. 21.2a–d). He was held out of spring practice while he completed rehabilitation and was able to RTS for summer workouts starting in June (6 months post-op). His shoulder was functioning well until he sustained a recurrent dislocation after he was tackled during a practice 1 week before the opening game of the season. This dislocation required a formal reduction. His current symptoms are mild shoulder pain with no significant weakness or loss of motion. He has had no recurrent instability episodes. He presented to discuss treatment options.

Physical Exam

When performing a shoulder physical exam, it is important to expose both shoulders adequately, maintaining modesty in females. This allows the examiner to look for any visible atrophy or side-to-side differences in appearance. In a patient with a history of a shoulder dislocation, the examiner must pay special attention to the muscle bulk of the deltoid and teres minor as the axillary nerve can be injured during a dislocation, and while uncommon, an axillary motor nerve palsy can develop. It is imperative this be documented preoperatively if it exists. Once the visual inspection is complete, the shoulder girdle is palpated for any areas of tenderness. The sternoclavicular joint, clavicle, acromioclavicular joint, bicipital groove, and greater tuberosity should be palpated. The shoulder is then taken through active and passive range of motion testing in all planes and compared to the non-injured side. In a patient who has sustained a recent dislocation, the position of instability is avoided. Strength

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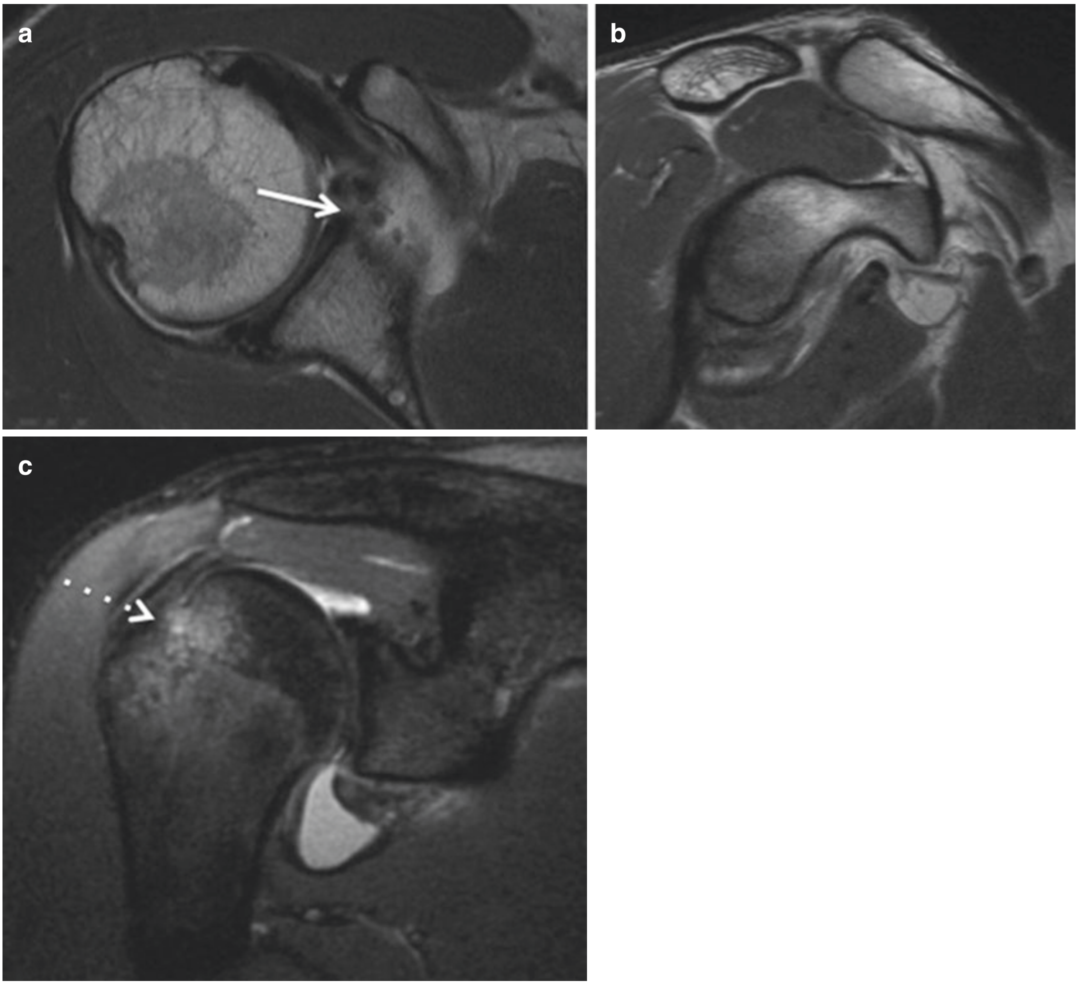

Fig. 21.1 (**a**–**c**): Proton density axial (**a**) and sagittal (**b**) and inversion recovery coronal magnetic resonance images following the patient's initial dislocation. There is significant fluid present in the joint. The axial (**a**) image demonstrates an anteroinferior labral tear (solid white arrow), while the sagittal (**b**) image shows no appreciable bone loss or bony component to the Bankart. The coronal (**c**) image demonstrates a small Hill-Sachs lesion (dashed white arrow)

testing of the deltoid and rotator cuff muscles follows, comparing side-to-side differences. Once this is complete, the patient is taken through a battery of special tests including an apprehension and relocation test, load and shift test, O'Brien's test, and Jerk test. There are other special tests that can be performed, but these are specific to a patient with a history of glenohumeral instability. The examiner should also evaluate the patient for a sulcus sign and perform Beighton score testing, as positive findings may suggest global ligamentous laxity or allude to an undiagnosed collagen disorder. Finally, the neurovascular status of the upper extremity is examined, paying close attention to the motor and sensory function of the axillary nerve by checking the posterior deltoid motor function and the skin sensation lateral to the lateral border of the acromion.

The physical exam for this patient can be divided into the current physical exam and the exam from his initial dislocation last season prior to his arthroscopic stabilization. His previous physical exam, performed 1 week after his dislocation, demonstrated full active and passive ROM, no strength deficits, no neurologic deficits, and a positive apprehension and relocation test. His current physical exam, performed 10 days after his most recent dislocation, demonstrated full ROM

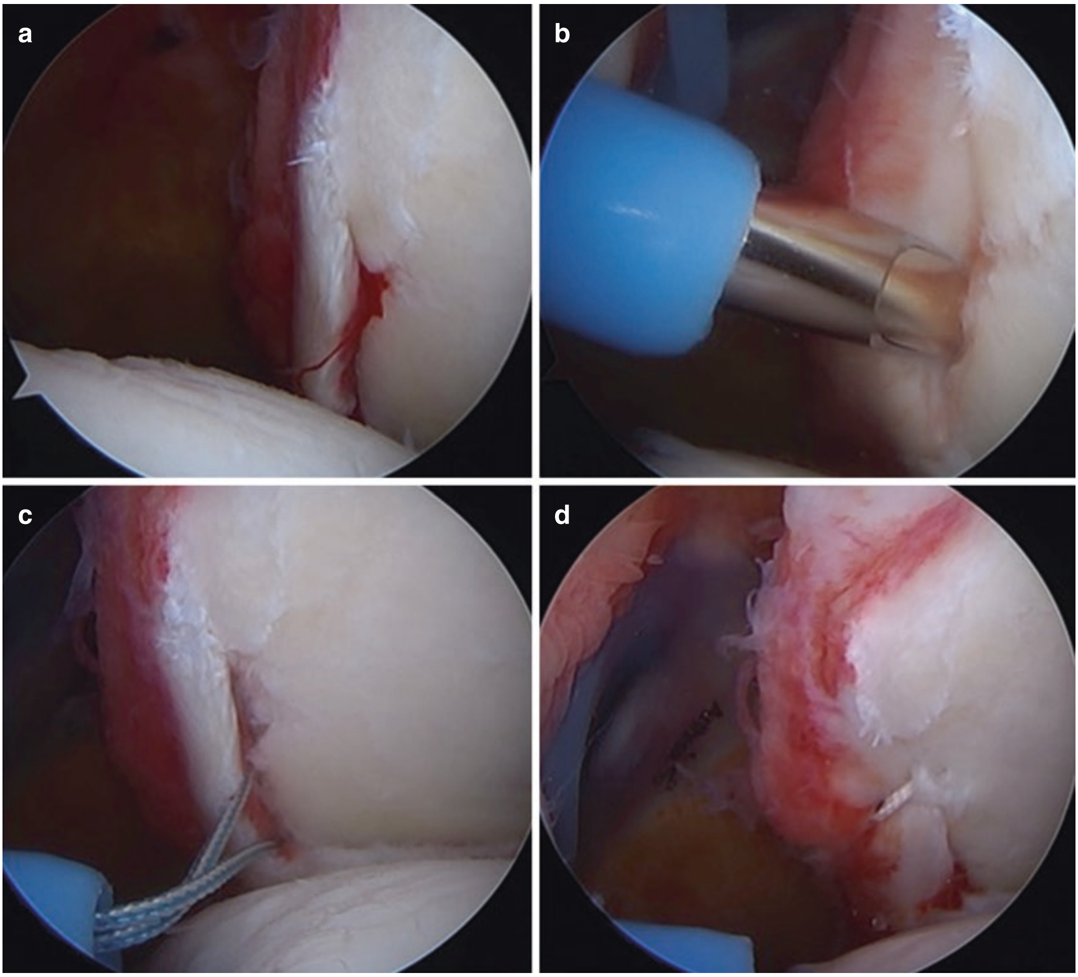

Fig. 21.2 (**a**–**d**): Arthroscopic images from the initial Bankart repair. The Bankart lesion is seen in (**a**), while (**b**) demonstrates the use of the arthroscopic shaver to debride the frayed edges of the labral tear as well to decorticate the glenoid bone to aid in healing. (**c**) demonstrates shuttling of sutures through the capsule and labrum, while (**d**) shows the final construct once the sutures have been placed into knotless anchors

and symmetric strength, a positive apprehension and relocation test, and now a positive load and shift test anteriorly with pain and increased translation compared to his previous exam. He has remained neurovascularly intact with no evidence of axillary nerve dysfunction. He had a negative sulcus sign and Beighton scoring of 0/9.

Imaging

While the history and physical exam provide essential information to help determine treatment strategies for patients with shoulder dislocations, diagnostic imaging is critical especially in recurrent instability. Every patient with a history of a shoulder dislocation should obtain a series of shoulder radiographs including anteroposterior (AP), axillary (to ensure the shoulder is located), and scapular Y views. These should be performed in the emergency room after formal reduction is performed. Additional views including a west point view, Stryker notch view, Velpeau view, and others can be useful when looking for Hill-Sachs lesions or if the patient cannot obtain an axillary view. Following radiographs, advanced imaging in the form of a MRI is commonly ordered. The MRI is most useful in the acute setting of a shoulder dislocation as the hemarthrosis that commonly occurs with a shoulder dislocation allows the MRI to function like an MR arthrogram, highlighting the pathology even more effectively. The purpose of the MRI is to evaluate the labrum, chondral surfaces, glenohumeral ligaments, capsule, etc. A new MRI was obtained on this patient following his most recent dislocation, which demonstrated a large bony Bankart fragment (Fig. 21.3a–d) in addition to an anteroinferior labral tear extending from 3:00 to 6:00 on the clock face. There is a moderate-sized hemarthrosis, indicating this was performed in the relatively acute setting. The new MRI was noticeably different from the MRI following his initial dislocation, which showed only a soft tissue Bankart (Fig. 21.1a–c). There was no evidence of a humeral avulsion of the glenohumeral ligament (HAGL) lesion on either MRI, something that should be carefully scrutinized in each patient with a history of shoulder dislocation.

While MRI is very useful for soft tissue anatomy, a computed tomography (CT) scan is superior when evaluating bony anatomy. The CT scan can evaluate for and quantify the amount of glenoid bone loss and can look for a Hill-Sachs lesion. The timing of the CT scan is less critical than the MRI as the hemarthrosis does not increase the sensitivity or specificity of this test. As this patient had failed a prior soft tissue procedure and had evidence of bone loss on his MRI, a CT scan

Fig. 21.3 (**a**–**d**): Proton density axial (**a**), sagittal (**b**–**c**), and coronal (**d**) magnetic resonance images following the subsequent dislocation. Notice the large bony Bankart fragment (white arrows)

was obtained (Fig. 21.4a–c). In a first time dislocator without a significant bony glenoid component appreciated on MRI, it is debatable as to whether or not the benefit of obtaining a CT scan outweighs the cost and radiation exposure. Whether or not to obtain a CT scan in the primary setting is typically decided on a case-by-case basis, while in the setting of a failed arthroscopic stabilization, it has become routine in our practice. The CT scan on this patient demonstrated anteroinferior glenoid bone loss with a large bony Bankart fragment. As is often the case in someone with a history of an arthroscopic labral repair that subsequently failed and redislocated, this patient fractured his anteroinferior glenoid through the previous anchor sites. The amount of bone loss can be quantified using the CT scan to help guide treatment. This patient had 25% glenoid bone loss from the fractured fragment.

Diagnosis

The diagnosis of the patient in this case is clear: recurrent anterior shoulder instability in the setting of a failed previous arthroscopic stabilization,

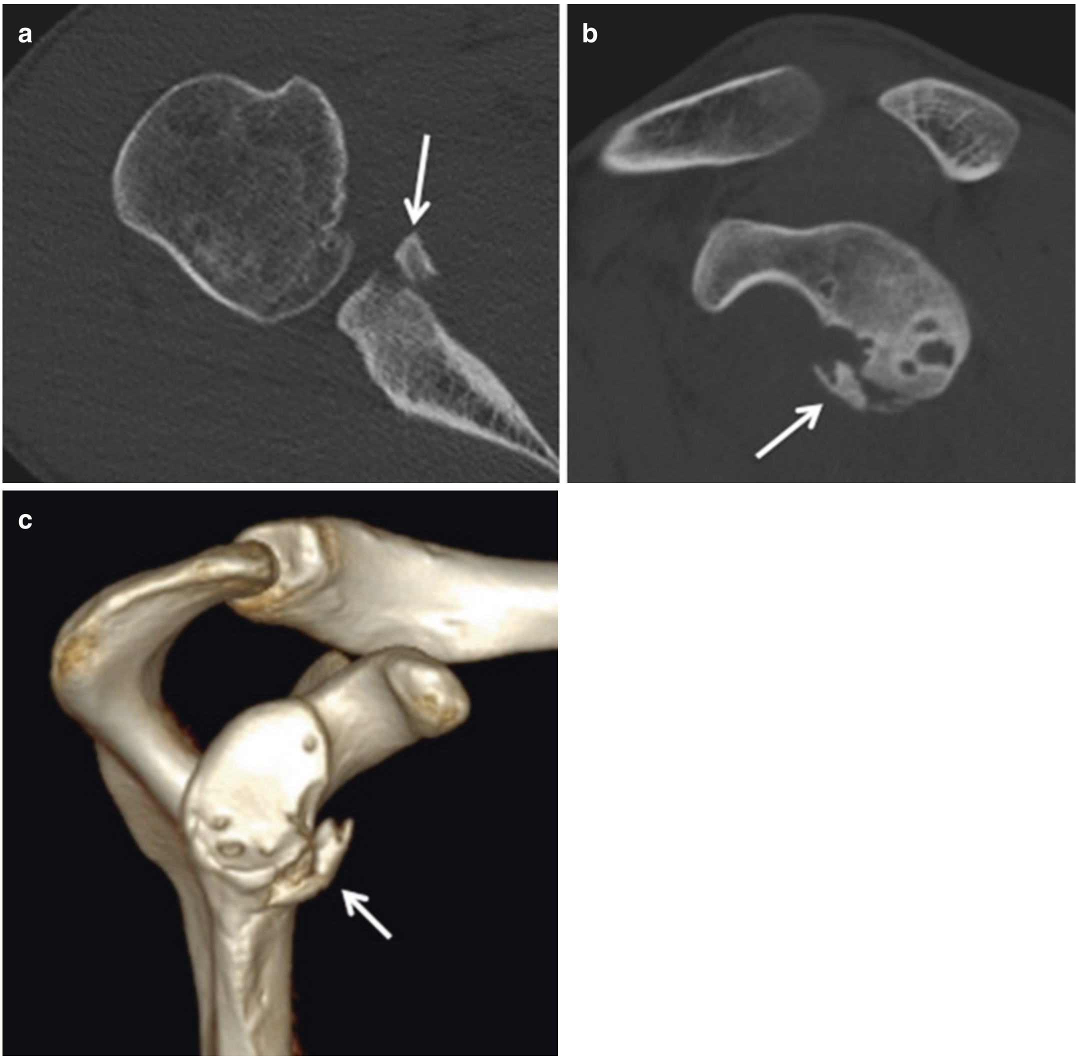

Fig. 21.4 (**a**–**c**): Axial, sagittal, and 3D reconstruction computed tomography images following the recurrent instability episode demonstrating the large bony Bankart lesion (arrows)

now with 25% glenoid bone loss. However, the other factors that must be evaluated include his age, collision sport, desire to RTS, and history of prior stabilization. A shoulder instability severity index score was developed by Balg and Boileau in 2007 to help guide treatment of patients with glenohumeral instability (1). Based on this scoring system, there are certain prognostic factors in our patient that increase his risk of recurrence following an arthroscopic stabilization. His age is slightly higher than the cutoff of 20 based on the instability score; however, he is still on the younger end of the spectrum, thereby increasing his risk of recurrence. He participates in a competitive, contact sport, both of which increase his likelihood of recurrence following an arthroscopic procedure. Although he had no significant shoulder hyperlaxity, he did have a Hill-Sachs lesion. Finally, he had loss of glenoid contour, causing the Hill-Sachs lesion to be off track (engaging) (2–4). When taken together, these factors confer an extremely high risk of recurrence for this patient following an arthroscopic stabilization (>70%). Failure after his previous technically well-done arthroscopic stabilization increases his recurrence risk even further.

Treatment

There are two difficult treatment decisions that must be made for this patient: how to treat his condition and when to treat him. The first issue is how to treat the athlete's pathology. Physicians taking care of athletes must understand that the natural history of an unrepaired shoulder instability lesion in these patients is poor (5–7). These athletes are significantly more likely to successfully return to play if they are treated operatively (7). Furthermore, if the athlete is allowed to continue to play a high-risk sport, it is likely the condition of the shoulder will worsen, possibly affecting the quality of the overall outcome. Treatment options for recurrent anterior shoulder instability include non-operative management, revision arthroscopic stabilization with or without a remplissage, open stabilization and capsular shift, and bony transfer procedures (Latarjet, Eden-Hybinette, distal tibial allograft, etc.). In our practice, we believe the Latarjet offers the specific subset of patients with this clinical presentation and findings the most predictable outcome of shoulder stability and ability to return to sport. Given this patient's history of a failed arthroscopic stabilization, glenoid bone loss, Hill-Sachs lesion, age, activity level, sport, and desire to compete in the NFL, he will be best served by a Latarjet in which his coracoid is cut and transferred to the anteroinferior aspect of the glenoid. However, one important caveat is that procedures such as the Latarjet are essentially nonanatomic, salvage procedures which have a good track record for reducing the likelihood of recurrent instability but are unlikely to allow full athletic overhead use of the shoulder. Hence, if this patient was an overhead athlete, the decision tree would be much different.

This procedure is typically performed on an outpatient basis with use of regional or general anesthesia. The patient is placed in the modified beach chair position, and after sterile prepping and draping and administration of antibiotics, a saber incision is made just off the lateral edge of the coracoid extending distally. Dissection is taken down to the deltopectoral interval where the cephalic vein is mobilized and retracted laterally, and the coracoid is exposed. The pectoralis minor is released from the medial aspect of the coracoid, and the coracoacromial ligament is transected, leaving approximately 5 mm of tissue attached to the coracoid for later repair.

A 90° saw blade is used to cut the coracoid approximately 20 mm proximal to the tip of the coracoid, taking care not to violate the coracoclavicular ligaments. Soft tissue is cleaned off of the undersurface of the coracoid, and this area is decorticated, all the while protecting the musculocutaneous nerve. A guide is used to drill two holes in the coracoid, and this is tucked away for later use. The subscapularis is then split at the 50-yard line in line with its fibers and is then elevated off of the capsule. A split in the capsule is performed, and the capsule is tagged for later repair. The anteroinferior portion of the glenoid is exposed and decorticated. If there is residual bone fragment here, this is removed as it is nonfunctional and may impede the fit and fixation of the coracoid transfer. The coracoid is then secured to the glenoid with K-wires, ensuring the edge of the coracoid is flush with the articular surface. If the graft is placed too lateral, it can accelerate arthritic changes in the shoulder, and if it is placed too medial, it loses some of its function. Once the graft is in the ideal position, one or two screws with washers are placed to secure the graft (Fig. 21.5a and b). The remnant coracoacromial ligament is repair to capsule, the split in the capsule and subscapularis are repaired, and the wound is closed in a layered fashion. A sling is applied to limit motion for the first 2 weeks.

Now that the type of treatment has been decided, the other, and often more difficult, decision that must be made is when to perform the Latarjet: acutely or at the end of the season. Once this contact athlete undergoes surgery, it is typically 6 months before he can RTS (8, 9). This particular athlete is at the start of his junior season, is a highly ranked wide receiver, and wants to play in the NFL. He also has significant glenoid bone loss. If the athlete were to have the Latarjet at the end of the season and attempt to RTS, he would undergo a brief period of shoulder immobilization (3–10 days) followed by early rehabilitation. Once he regained full pain-free ROM and strength, he would be allowed to RTS at approximately 7–21 days and may require the use of a brace. If he chose to undergo the Latarjet acutely, he would immediately be removed from competition. In this particular case, the athlete is at a high risk of recurrent shoulder dislocations given his sport (football) and glenoid bone loss. Furthermore, the season has not started yet. If there was one game left in the season, the argument could be made to allow the player to compete in his last game, accepting the risk of a recurrent dislocation, which has been shown to be a risk factor for development of shoulder arthrosis (10). However, taking all the factors in the particular case into consideration, we believe the most appropriate course for this patient is to remove the patient from competition and perform the Latarjet acutely.

Rehabilitation

Following a Latarjet procedure, the patient is placed into a sling with an abduction pillow at all times. They can remove the sling to perform elbow, hand, and wrist ROM exercises. After 2 weeks, the sling is worn during the day only and can be removed for sleeping. The patient's external rotation is limited passively to 45° ROM for the first 6 weeks to protect the subscapularis repair, while no restriction is set on forward elevation. Patients can work on grip strengthening

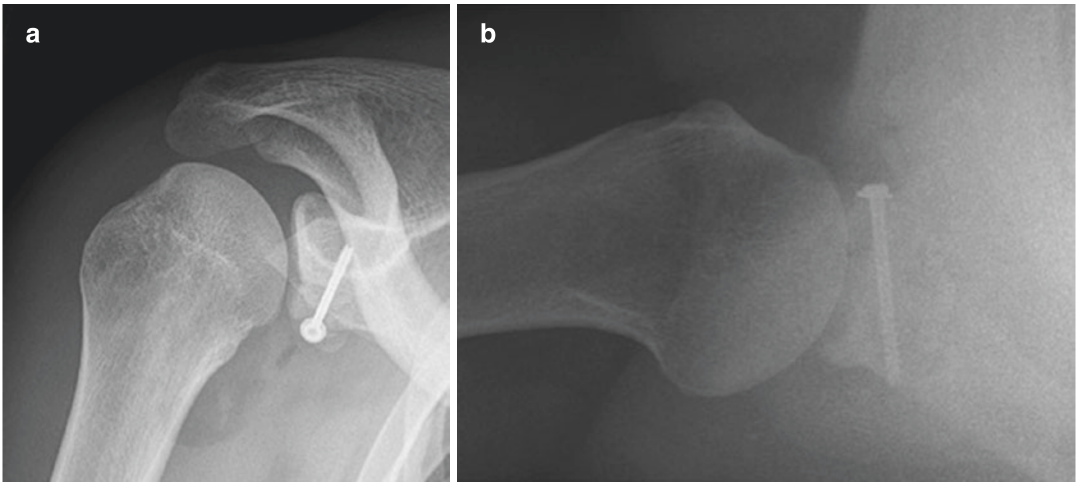

Fig. 21.5 (**a** and **b**): Coronal and axillary radiographs following the patient's Latarjet demonstrating excellent screw placement and position of the coracoid

and pendulums from weeks 0 to 3 and begin rotator cuff and deltoid isometrics from weeks 3 to 6. No active extension or internal rotation is permitted until 6 weeks. Once the patient hits the 6-week mark, the sling is discontinued. At this point they can progress their ROM as tolerated without restriction, slowly building toward full ROM. In weeks 6–8 patients begin light-resisted external rotation, forward flexion, and abduction. At 8–12 weeks they begin resisted internal rotation, extension, and scapular retraction. Finally, patients focus on closed chain scapular rehabilitation and functional rotator cuff strengthening. Therapists should pay particularly close attention to the anterior deltoid and teres minor. Scapular may be started at 2 weeks and should be maximized to allow the shoulder a firm foundation for all movements.

Outcomes

Several studies have reported encouraging outcomes following Latarjet procedures in athletes; however they have also reported complications including recurrent dislocations, nerve injury, infection, and others (11–13). Baverel et al. reported on 106 patients (110 shoulders) over 5 years who underwent open Latarjet by a single surgeon (14). Of these patients, 65 participated in collision/contact sports; there were 57 (54%) competitive athletes and 49 (46%) recreational athletes. The author's indication for Latarjet was a minimum of two dislocation/subluxation events, positive apprehension test, an instability severity index score greater than 2, and findings correlating to anterior instability on CT scans. At a mean follow-up of 46 months, three patients sustained a recurrent dislocation (two competitive athletes and one recreational athlete). Overall 95% of patients had an excellent/good level of satisfaction. Significant improvements in shoulder outcome scores were seen in these patients. No neurologic complications were reported in this patient cohort, although three patients necessitated hardware removal for subscapularis impingement, one patient sustained a graft fracture, and one patient had nonunion of their graft.

Similarly, Privitera et al. reported on 73 contact/collision athletes (average age at follow-up of 25.8 years (range, 15–54 years)) who underwent an open Latarjet (15). At a mean follow-up of 52 months, 6 (8%) of the 73 patients experienced a recurrent dislocation. Ten other patients (14%) had the feeling of instability without a dislocation. In regard to RTS, 49% of patients returned to their original sport at their preinjury level of competition, 12% of patients changed sports but remained at the same level of competition, and 14% of patients returned to their original sport at a decreased competitive level. The other 25% either reduced their level of competition and changed sport or discontinued sport participation. One very interesting finding from this study was that RTS rate was 72% when the Latarjet procedure was the patient's primary stabilization procedure, 75% when the patients had only one prior stabilization procedure, and dropped to 39% for those with two or more prior stabilization procedures ($p = 0.019$). No significant neurologic complications were reported in this group of patients.

Conclusion

Recurrent glenohumeral instability in a high-level contact athlete is a difficult problem to treat. Patients who have failed a prior well-done arthroscopic stabilization and present with glenoid bone loss are indicated for a Latarjet procedure. Timing of this procedure for the athlete is difficult and is a shared decision with the athlete (and possibly the athlete's parent, depending on age), coach, and physician. While general treatment guidelines can be followed, each player should be taken on a case-by-case basis.

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A 22-Year-Old Female Tennis Player with Shoulder Pain

22

Sarav S. Shah and Alan S. Curtis

History

A 22-year-old female collegiate tennis player (CG) presented with a 1-year history of increasing left shoulder discomfort. She described the pain as a "dull ache" accompanied by a feeling of generalized weakness in her left upper extremity. Initially, she could play through the pain; however, now the pain has become unbearable. At the start of the season, rest helped alleviate the pain; however, she expressed that currently there was an ache with any overhead activity and even activities of daily living especially in these past 2–3 weeks at the end of the season. The pain in the anterior aspect of the shoulder is exacerbated by overhead and repetitive actions, especially serving during the late cocking and early acceleration phases. She is at the end of her season, and in her words, she "barely made it through the playoffs." Today, her main complaint was pain in the anterior aspect of the shoulder exacerbated by overhead use. Of note, this is the first time she is seeking medical attention for this ailment; however, she had tried anti-inflammatory medications with little benefit. She has no pertinent past medical history.

Comprehensive Local and Distant Physical Exam

Optimal performance of the overhead throwing task requires precise mechanics that involve coordinated forces and motions to allow their summation in a collective mechanical linkage called the kinetic chain [1]. Each body part plays a specific role in the entire motion [2]. The feet are contact points with the ground and allow maximum ground reaction force for proximal stability, while the legs and core are the mass for the stable base and responsible for the largest amount of force generation. Distally, the shoulder is the funnel for force transmission and the fulcrum for stability during the rapid motion of the arm, while the arm and hand are the delivery mechanism of the force to the racquet [1, 3, 4]. The body works as a unit to achieve optimum overhead throwing function and can fail as a unit in altered performance. There may be alterations in anatomy and/or physiology, which can combine to produce an alteration in the normal mechanics that may create decreased efficiency, impaired performance, or increased injury risk [5, 6].

Therefore, the evaluation of overhead athletes with disabled throwing shoulder (DTS) (a general term that describes the limitations of function that exist in symptomatic overhead athletes) needs to be comprehensive. Although not performed on this patient, a formal analysis of mechanics is an evaluation component that may

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be beneficial. This involves an assessment of the pertinent normal mechanics (i.e., independent degrees of freedom representing key positions and motions in the overhead tasks called nodes), as well as identification of all pathoanatomic factors that may exist in the shoulder. There is specific methodology for evaluation of the presence or absence of specific nodes in tennis [2, 7, 8]. This examination can identify anatomic areas and mechanical motions that may be contributing to the symptoms and suggest areas for more detailed evaluation. This evaluation can be done by observational analysis of the service motion.

Specific tennis node evaluation (Table 22.1) includes:

1. *Foot position* – evaluate hip and/or trunk flexibility and strength; pathomechanics may lead to increased load on the trunk or shoulder.
2. *Knee motion* – evaluate hip and knee strength; pathomechanics may lead to increased load on the anterior shoulder and medial elbow.
3. *Hip motion* – evaluate hip and trunk flexion flexibility and strength; pathomechanics may lead to increased load on the shoulder and trunk.
4. *Trunk motion* – evaluate hip, trunk, and shoulder flexibility; pathomechanics may lead to increased load on the anterior shoulder and possibly "slow arm" from increased load on abdominals.
5. *Scapular position* – evaluate scapular strength and mobility; pathomechanics may lead to increased internal and external impingement with increased load on rotator cuff muscles.
6. *Shoulder/scapular motion* – evaluate scapular and shoulder strength and flexibility; pathomechanics may lead to increased load on the anterior shoulder with potential internal impingement.
7. *Shoulder over shoulder* – evaluate front hip strength and flexibility with back hip weakness; pathomechanics may lead to increased load on abdominals.

Table 22.1 Tennis nodes and potential sites of increased strain with deleterious motions

Node	Normal mechanics ("good")	Deleterious motions ("bad")	Potential increased strain on kinetic chain
1. Foot position	In line, foot back	Foot forward	Increased load on trunk or shoulder
2. Knee motion	Knee flexion greater than 15	Decreased knee flexion less than 15	Increased load on anterior shoulder and medial elbow
3. Hip motion	Counter-rotation with posterior hip tilt	No hip rotation or tilt	Increased load on shoulder and trunk; inability to push through increasing load on abdominals
4. Trunk motion	Controlled lordosis; X-angle approximately 30°	Hyperlordosis and back extension; X-angle >30° (hyper) or <30° (hypo)	Increased load on abdominals and "slow arm"; increased load on anterior shoulder
5. Scapular position	Retraction	Scapular dyskinesis	Increased internal/external impingement with increased load on rotator cuff muscles
6. Shoulder/scapular motion	Scapulohumeral rhythm with arm motion (scapular retraction/humeral horizontal abduction/humeral external rotation)	Hyper-angulation of humerus in relation to glenoid	Increase load on anterior shoulder with potential internal impingement
7. Shoulder over shoulder position	Back shoulder moving up and through the ball at impact, then down into follow-through	Back shoulder staying level	Increased load on abdominals
8. Long axis rotation	Shoulder internal rotation/forearm pronation	Decreased shoulder internal rotation	Increased load on medial elbow

X-angle = measurement of hip/trunk separation angle; the angle between a horizontal line between anterior aspect of both acromions and horizontal line between both anterior superior iliac spines when viewed from above. Of note, nodes 1–6 occur prior to the acceleration phase of the service motion whereas numbers 7 and 8 occurs after ball impact

8. *Long-axis rotation* – evaluate glenohumeral rotation; pathomechanics may lead to increased load on the medial elbow.

On physical examination of her left upper extremity, CG had normal glenohumeral active and passive forward elevation and external rotation. In the supine position, she had about a 25° internal rotation deficit on the left compared to 10° on the right with the scapula stabilized, which was not overly remarkable. Regarding scapular strength and mobility, she had significant scapular protraction and winging of her scapula as she elevated the shoulder into the overhead with 4/5 strength against resistance. Regarding shoulder strength, she demonstrated mild weakness 4/5 with supraspinatus and infraspinatus strength testing and 5/5 deltoid strength. On physical examination of her bilateral lower extremities, hip, trunk, and knee strength and flexibility was within normal limits and equal compared to the other side.

Specific examination for shoulder pathology showed she was tender over the anterior aspect of the shoulder, specifically over the biceps and the supraspinatus insertion. She had a positive Jobe empty can sign with negative drop arm, Hornblower's sign, and lift-off. Also, she had a positive O'Brien's and crank test, but a negative Yergason's test. She was non-tender over the AC joint with a negative cross-body adduction test. She did have a positive apprehension and apprehension suppression test, but it was more of a pain issue rather than a feeling of instability. Additionally, she had a mild sulcus sign which stabilized appropriately with rotation. Of note, she had a negative Kim and jerk test.

Imaging

Although the timing of imaging is debatable, in general X-rays (Grashey, scapular Y, and axillary) are obtained at the time of the first office visit to rule out bony abnormalities and evaluate the shape of the acromion, glenohumeral joint congruity, and AC joint. Typically, advanced imaging is not required at the onset. An MRI is used to delineate intra-articular pathology within the glenohumeral joint. Additionally, in cases of suspected labral pathology, an MRA should be considered. Although, some may argue the increased accuracy or sensitivity in the diagnosis of SLAP lesions purported with MRA versus MRI [9], it has become fairly standard in suspected cases of labral pathology as MRA confers a reported 89–100% sensitivity, 69–91% specificity, and 74–92% accuracy for the detection of SLAP lesions [10–12].

Her films demonstrated closed growth plates. Also, there was a slight downslope to the acromion on the Grashey view. There was well-maintained glenohumeral joint space with no evidence of osseous abnormalities. Because of the chronic nature of the patient's pain and disability, the decision was made to get an MRI of her left shoulder while holding off on an MRA for now. There was also an abnormal rounded 5 × 5 m signal to the anterior superior labrum associated with abnormal linear signal interposed between the anterior superior labrum and glenoid. This was consistent with a small superior labrum anterior posterior (SLAP) tear. Her MRI also showed a small paralabral cyst anterior to the biceps (Fig. 22.1). Also, there was a small anterior Bankart tear with a diminutive, attritional appearance to the anterior inferior labrum (Fig. 22.2). Of note, the biceps tendon and posterior and inferior labrum had a normal appearance. Additionally, there was slight undersurface degeneration with possible partial tearing of the undersurface of the supraspinatus (Fig. 22.1).

Differential Diagnosis for Patient CG in the Setting of Disabled Throwing Shoulder (DTS)

1. Subacromial bursitis/subacromial impingement
2. Scapular dyskinesis
3. Multidirectional instability (MDI)
4. Superior labrum anterior posterior (SLAP) tear
5. Partial rotator cuff tear

The impression at this time was bursitis/impingement secondary to poor scapular control, thus functional impingement. We cannot rule out intra-articular issues completely. There was also a stable paralabral cyst, which was not felt to be a

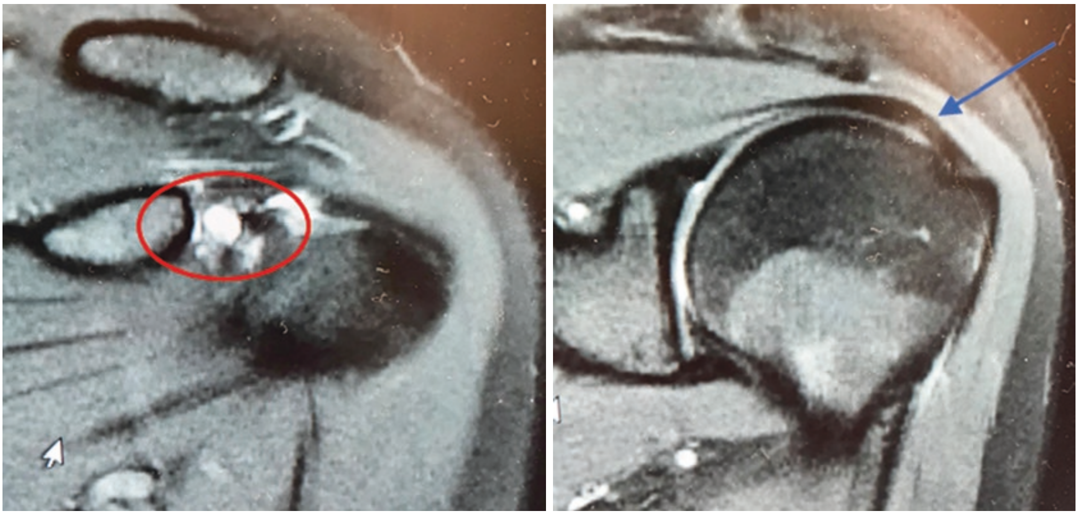

Fig. 22.1 Magnetic resonance coronal imaging showing a small paralabral cyst anterior to the biceps (red circle). Also, there is slight undersurface degeneration with possible partial tearing of the undersurface of the supraspinatus (blue arrow) in a 22-year-old female tennis player

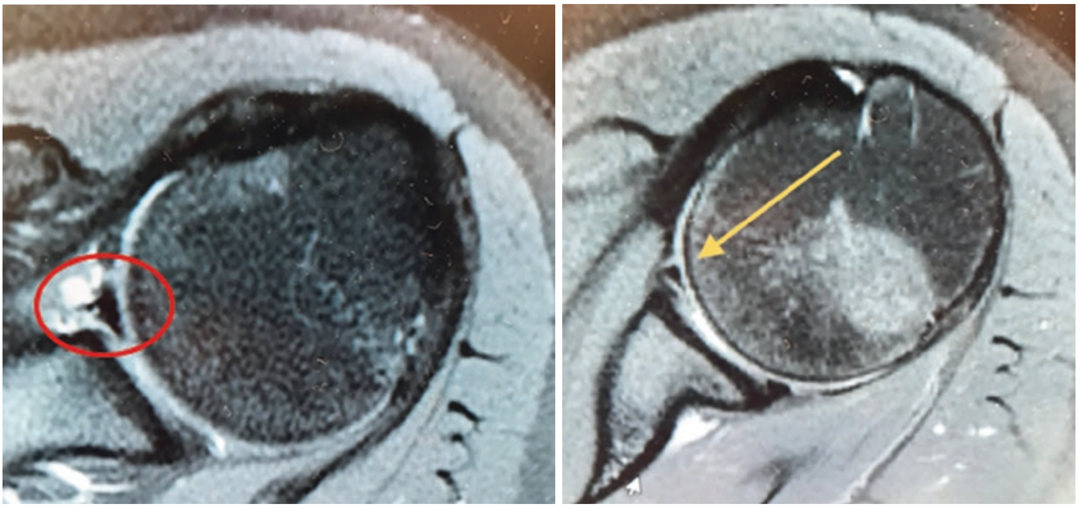

Fig. 22.2 Magnetic resonance axial imaging showing a small anterior Bankart tear (red circle) with a diminutive, attritional appearance to the anterior inferior labrum (gold arrow) in a 22-year-old female tennis player

primary contributor to her symptoms. There was an underlying component of mild to moderate multidirectional instability as well with no dislocation. Correspondingly, there was some slight undersurface degeneration and possible partial tearing of the undersurface of the supraspinatus consistent with her symptoms.

Non-operative Treatment Options

1. Physical therapy: program with concentration on improving scapular control and core and rotator cuff strengthening with the goal of improving the stability of the shoulder
2. Intra-articular and bursal corticosteroid injection under fluoroscopic guidance

Operative Treatment Options

1. Arthroscopic shoulder anterior capsulorrhaphy with interval plication
2. Arthroscopic shoulder partial rotator cuff debridement/repair +/− subacromial decompression
3. Arthroscopic shoulder SLAP repair
4. Open anterior capsular shift

Progression of Recovery and the Outcomes of the Non-operative Treatments in Case

After discussion with the patient and her parents, the plan was to move ahead with an intra-articular and bursal corticosteroid injection under fluoroscopic guidance, wait 2 weeks to allow the shoulder to calm down, and then start a rigorous physical therapy program with concentration on improving scapular control and core and rotator cuff strengthening to improve the stability of the shoulder.

After a 2-month follow-up period, she was doing extremely well. The pain in the shoulder was gone. She had increased scapular control and less evidence of postural impingement. She had improved strength and was just starting to get back onto the court with ground strokes. Another month later (3 months postinjection), she was seen again prior to returning to school. At this point, she had a very good range of motion and a stable scapula. There was mild multidirectional instability which continued to remain not significantly symptomatic. Her anterior shoulder pain had seemingly resolved.

In September (4 months postinjection), she returned to school. She continued to play high-level tennis at the collegiate and club level with improved serve mechanics. She was having a good season until about 3 months into the season. During a tournament, she had more pain along with discomfort in her shoulder, and after a very hard serve, she felt a distinct, sharp pain in her shoulder. She was unable to play after this point. The patient presented to the office after this event. On examination that day she had significant symptoms, worse than her initial presentation 7 months prior. She was very tender over the rotator interval. Symptoms were markedly worse on this examination. Apprehension and apprehension suppression testing were quite worrisome as she was very uncomfortable. The impression at that time was a rotator interval sprain due to a subluxation event. It was evident that the multidirectional instability component had worsened. A repeat MRI was obtained for this acute on chronic condition that seemingly has worsened. The images show significant fluid in the rotator interval. Again, there was demonstrated an abnormal rounded 5 × 5 m signal to the anterior superior labrum associated with abnormal linear signal interposed between the anterior superior labrum and glenoid; this was along with a small paralabral cyst anterior to the biceps. Also, there was a small anterior Bankart tear with a diminutive, attritional appearance to the anterior inferior labrum. There were no obvious subacromial changes. There is no bursitis at this time and the rotator cuff has not changed in appearance since the prior study.

At this point in time, she had been having problems for over 2 years and had completed all conservative measures. After a long discussion with the patient and the parents, the decision was made to move forward with surgical intervention. The plan was for exam under anesthesia (EUA) and arthroscopy of the shoulder with anterior band of the inferior glenohumeral ligament (IGHL) plication along with rotator interval plication. Also depending on the arthroscopic findings, plan for a SLAP debridement/repair and rotator cuff debridement, if needed.

Surgical Treatments/Techniques and Outcomes

Patient CG was brought to the operating room where a careful examination under anesthesia of both shoulders was undertaken. There was a definite right/left difference in terms of anterior slide. It was worse on the affected left side. She had a moderate sulcus that does improve with external rotation, however. She was stable posteriorly.

Arthroscopy revealed a moderately inflamed joint, especially in the interval region. She had an attritional middle glenoid ligament along with an intact but stretched-out inferior glenoid ligament and inferior capsule. Posteriorly the labrum and the posterior capsule were within normal limits. Her anterior inferior labrum was somewhat attritional with fraying and a small tear. The paralabral cyst was simply a fold of tissue. The superior labrum was well attached. The undersurface of the cuff had some mild fraying. We debrided the mild fraying of the cuff and some degenerative labrum anteriorly.

At this point, we felt plication of the anterior inferior labrum and anterior band of the IGHL would be beneficial in an effort to restore some of the normal anatomy and biomechanics. One of the main pathomechanical features in DTS is a loss of ideal concavity compression and functional glenohumeral stability [1]. This can result from a combination of alteration of muscle force couples, scapular dyskinesis [13, 14], internal rotation deficit/total rotation motion deficit [15, 16], rotator cuff disease [17], and/or labral injury [17]. The combination results in the performance symptoms, i.e., loss of velocity and accuracy along with clinical symptoms of pain, clicking, sliding, weakness, and injury [1].

Due to the fact the labrum is fairly attritional, we used a technique placing a 1.3 mm suture-based anchor at the anterior inferior margin of the glenoid and then a second anchor above the attachment of the anterior inferior glenohumeral ligament. We then performed a pinch-tuck procedure. We pinched a centimeter of capsule away from the labrum, advanced it up, and then passed it under the intact labrum. In this manner, we plicated the anterior inferior glenoid ligament and improved the bumper effect of the diminutive labrum. Above that there was actually just attritional tissue. With the third anchor, we caught some capsular tissue from just off the front of the subscapularis to extend the bumper above the midpoint of the glenoid rim (Fig. 22.3).

Given the fact the patient had a moderate sulcus sign and very attritional tissue in this region, we did place a stitch in the interval. Staying lateral, we used an absorbable PDS stitch. At the very lateral margin of the interval, we caught a centimeter of the coracoacromial ligament above the portal and the very top of the subscapularis right at the insertion point. In this manner, we basically just slightly tightened the interval but did not close it down, as it is important not to over-constrain an overhead athlete.

Postoperatively she was kept in a shoulder sling for 5 weeks. She came out of the sling only to do elbow, wrist, and hand exercises. After 2 weeks, she was allowed 0–90° of forward flexion with the arm internally rotated. She was allowed external rotation only to about 15° in an effort to really give this shoulder a chance to heal and stabilize. At 5 weeks the shoulder sling was removed. She was allowed to do active elevation as tolerated.

We saw her back 4 weeks post procedure. At this point we start formal physical therapy. It has been our approach with instability patients, especially in this age group, to actually delay the physical therapy hands-on component as they typically will get back a fairly moderate amount of range of motion just by doing a home exercise program. This obviates or decreases the possibility that a physical therapist would stretch out the repair by doing overzealous passive range of motion. At 2 months, we evaluate motion, and then we specifically direct the physical therapist in their approach, again allowing mostly active range of motion and active assisted, avoiding passive range of motion, and then starting scapular stability exercises and progressing to rotator cuff exercises usually at 3 months. A core exercise program can be done during this entire period. At 4 months we allow ground strokes. At 5 months we allow serving.

In this case, CG progressed exactly as we would have expected during this period. She was hitting ground strokes without pain at 4 months post procedure. She returned to serving, most second serves, without really pushing it the 1 month after that (5 months post procedure). By 6 months post procedure, she felt her shoulder is stable, and she has returned to full play at prior performance level. She has not followed up for any issues since then.

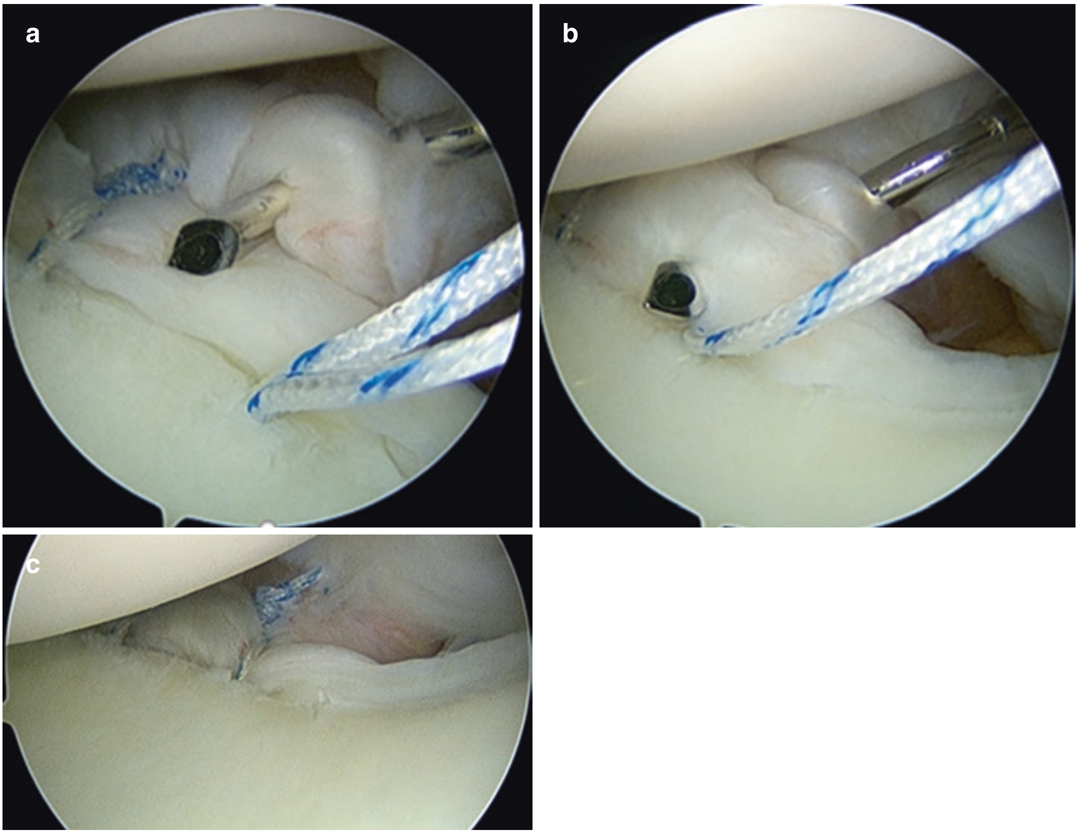

Fig. 22.3 Arthroscopic images from the lateral decubitus position for a 22-year-old female tennis player. (**a**) Shows a spectrum hook entering the anterior band of the IGHL, (**b**) shows a spectrum hook entering the anterior inferior labrum, and (**c**) shows the completed anterior Bankart repair with capsulorrhaphy (pinch-tuck procedure with incorporation of the IGHL into the anterior inferior labrum). *IGHL* inferior glenohumeral ligament

Summary of the Conclusions from the Case

An important take-home point about dealing with the overhead athlete in this situation is to take caution with an initial MRI. Often the initial MRI does show labral pathology, but it is not the primary cause of symptoms. An immediate response might be to proceed with labral surgery, but it is usually not the issue nor is it productive. There tends to be a multifactorial component to the pain, including a lack of functional glenohumeral stability, scapular dyskinesis, and rotator cuff inflammation. All of these issues need to be carefully evaluated and addressed. Our feeling is that surgery is rarely the first option in an overhead athlete. After the athlete has failed a rigorous and well-monitored physical therapy program, and if they are not progressing, then at that point, surgery can be entertained. We tend to stay away from SLAP repairs in this group as the return to play at the same level has not been reliable; only 63% of overhead athletes returned to their previous level of play according to a recent systematic review of type II SLAP lesion repairs [18]. Instability findings in these patients can exacerbate the overlying problem. As was shown in this case, when the multidirectional instability became the major issue, restoring the stability of the joint and balancing out her capsule did lead to resolution of her symptoms. With careful attention to detail during surgery, combined with a well-monitored postop rehabilitation program, we can get these athletes back on the court.

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23

Posterior Instability/Posterior Labral Injury in an Overhead Athlete

Fotios Tjoumakaris, Richard Campbell,
and James P. Bradley

Introduction

Posterior shoulder instability is less common than anterior instability, comprising 2–12% of shoulder instability patients [1]. While acute posterior dislocation can lead to posterior instability, it is more commonly observed in competitive athletes participating in upper extremity-dominant sports, such as baseball, volleyball, weight lifting, and football [2, 3]. It is also observed in patients participating in military training [4]. Posterior instability can be a sequela of injury to various structures including the glenoid, labrum, capsule, or glenohumeral ligaments [4]. As a result, posterior instability can present multiple ways, often making diagnosis and treatment difficult. Patients may present with frank dislocation (rare), recurrent posterior subluxation, or only pain. Advancements in high-resolution diagnostic imaging and arthroscopic surgical technique have led to high rates of stabilization, pain reduction, and return to competitive sport participation [5, 6]. The following clinical vignette explores the diagnosis, management, and follow-up of posterior instability in a high-level athlete.

History

J.S. is a 20-year-old female, sophomore collegiate volleyball player, presenting with 1 year of pain in her left shoulder. She has played volleyball competitively for the last 6 years as an outside striker. She reports an insidious onset of aching deep shoulder pain that began at the start of her previous volleyball season. She denies traumatic injury or dislocation. She was able to play through the season using anti-inflammatory medicine and heat for pain relief. Following the end of the season, she started a 3-month rotator cuff and scapular stabilization strengthening regimen, along with daily NSAID use for 3 weeks.

One month ago she began training for the current season, with severe recurrence of her pain. The pain begins 10 minutes into volleyball activities and lasts for 24 hours. Throughout the month, her pain has become progressively worse and has recently begun limiting her playing ability. At its worst, the pain is an 8/10 but decreases to 4/10 with rest. She now has difficulty warming up prior to practice. Serving and overhead hitting

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worsen her symptoms. Ice and NSAIDs partially alleviate her pain. She reports shoulder weakness and decreased serve velocity. She notices clicking with forward flexion. She denies instability, numbness, or shooting pain down her arm.

Physical Exam

General Exam

She is 6′0″ tall and weighs 150 pounds. On inspection, there is no obvious shoulder or scapular asymmetry, atrophy of the deltoids, or atrophy of the periscapular muscles. Scapula winging is not noted.

She has tenderness to palpation in the posterior aspect of her left shoulder capsule. Both active and passive range of motion are symmetric and full; however, she reports pain in her left shoulder when held in flexion, adduction, and internal rotation.

Strength testing reveals 5/5 strength with shoulder flexion, extension, abduction, and internal and external rotation. However, her effort in flexion and internal rotation is limited secondary to pain. There are no sensory deficits and she has symmetric palpable radial pulses.

Specific Exam Maneuvers

Pain and 1+ posterior glide are noted on the posterior load and shift test. O’Brien’s test and the dynamic sheer test are also positive with pain “deep in her shoulder.” She also demonstrates a positive Kim test and positive jerk test findings. The apprehension test is negative, as are Neer and Hawkins impingement signs. She has no sulcus sign and has normal laxity in other joints.

Imaging

Radiograph

Left shoulder anterior-posterior (AP), scapular Y, and axillary lateral plain radiographs were obtained in the office. AP and scapular Y radiographs are used to assess for fractures, dislocations, and osseous lesions [7]. While unlikely given her atraumatic history, these injuries should not be missed. No fractures or dislocations are present on AP radiographs (Fig. 23.1).

Axillary-view radiographs can be used to assess for osseous pathology such as a bony Bankart lesion or reverse Hill-Sachs lesion [7]. No osseous pathology is noted on her axillary radiographs (Fig. 23.1). This is expected given her lack of acute dislocation or traumatic injury.

CT

Given the low suspicion for osseous lesions on plain radiographs, a computed tomography (CT) scan was not obtained. If there was concern for a bony Bankart, CT imaging may be useful.

MRI

Magnetic resonance imaging with intra-articular contrast (MRI arthrography) is obtained 1 week after the initial office visit. The contrast aids in visualization of the labrum and delineation of tears. The MRI arthrogram demonstrated a posterior labral tear and Hill-Sachs lesion (Fig. 23.2). There was no evidence of periosteal stripping, paralabral cysts, or atrophy/tears of the rotator cuff or biceps tendon.

Diagnosis

The differential diagnosis for a young, active patient with shoulder pain is exhaustive. Diagnoses considered in her case included superior labral anterior-posterior (SLAP) tear, isolated posterior labral tear, humeral avulsion of the glenohumeral ligament (HAGL), multidirectional instability, acute rotator cuff tear, and radiculopathy.

Her young age and repetitive overhead activities make instability of some sort more likely. This is further supported by her “deep” shoulder

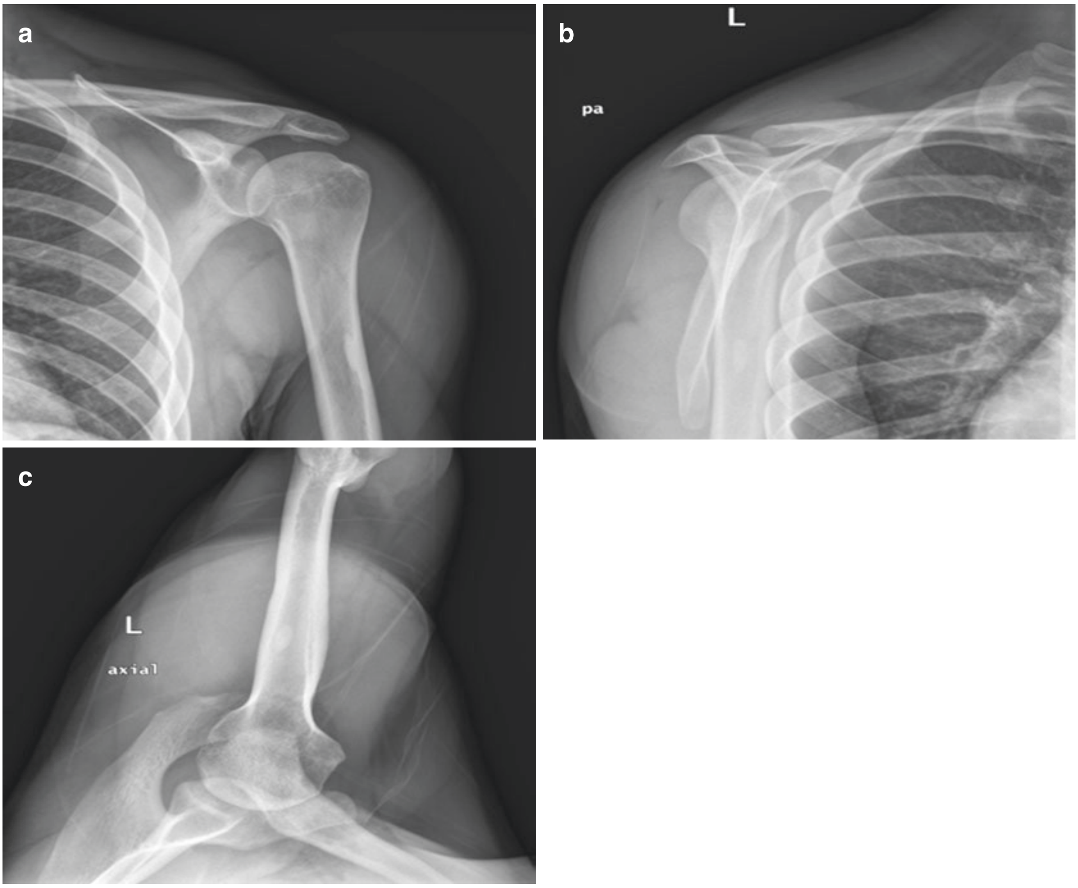

Fig. 23.1 Unremarkable, plain radiographs of the left shoulder. (**a**) Anterior-posterior. (**b**) Scapular Y. (**c**) Axillary

pain. Range of motion (ROM) and strength are often normal with instability injuries. ROM may be limited by impingement or adhesive capsulitis, which are more common in older patients. Strength deficits are indicative of a muscle or tendon injury and can be seen with paralabral cysts compressing the suprascapular nerve; however, pain with resistance while the shoulder is flexed and internally rotated is indicative of posterior labral injury and subsequent instability. The lack of numbness or shooting pain makes a neurological etiology less likely. This is further supported by a lack of atrophy, scapula winging, and sensation deficits on exam.

The diagnosis of instability is further supported by a positive O'Brien's test and dynamic sheer test. The instability was localized to the posterior labrum by the positive jerk test and Kim test.

The diagnosis of posterior instability secondary to an isolated posterior labral tear is confirmed by the MRI arthrogram results.

Treatment

Treatment options for posterior labral tear with instability include conservative management (physical therapy, anti-inflammatory medicine, and ice), arthroscopic repair, and open repair.

Conservative

She reported 3 months of conservative treatment under the direction of her athletic trainer. While 6 months of conservative treatment is considered

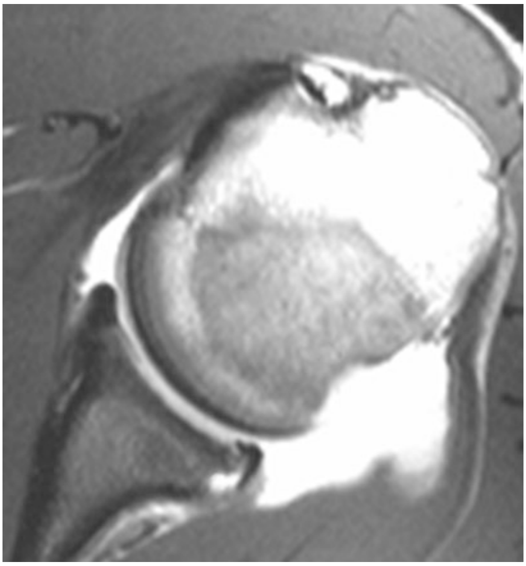

Fig. 23.2 T2-weighted MRI arthrogram demonstrating posterior labral tear and Hill-Sachs lesion

standard care before surgical intervention, her collegiate level of activity and failed 3-month physical therapy indicated that she would likely fail conservative measures.

Surgery

Because her current season had not started, she was eligible for a medical hardship waiver. She opted for season-ending surgical intervention instead of continued conservative management. Options for surgical intervention were discussed, including the pros and cons of arthroscopic and open procedures, possible complications, and the postoperative rehabilitation process. Due to the risk of significant complications associated with open procedures, such as nerve injury, and the procedural and biomechanical benefits of arthroscopic repair [8], she elected to undergo arthroscopic surgical repair. She was consented for left shoulder arthroscopy with arthroscopic labrum debridement and repair under general anesthesia with an interscalene nerve block.

The procedure was performed under general anesthesia with an interscalene nerve block. In the OR she was placed in the lateral decubitus position with the arm in 10 lbs of traction, 20° of flexion, and 45° of abduction. 7-mm cannulas were placed in posterior and anterior port sites. An arthroscopic examination was performed and the diagnosis was confirmed. No tears or degeneration was found in the surrounding structures.

The labrum was elevated off of the posterior margin of the glenoid, and the bone edge was slightly debrided with an arthroscopic shaver. An accessory portal was established to assist in anchor placement. Once adequately mobilized, three short 2.4-mm knotless anchors were placed along the posterior glenoid rim 3 mm apart. Prior to anchor placement, pilot holes are drilled into the glenoid face. The drill guide is placed at a 45° angle on the glenoid face to allow for protection of articular glenoid cartilage. A suture passing device is used to pass a shuttle suture around the labrum/capsule complex, which is exchanged for a labrum suture tape stitch made of polyethylene in a “cinch” stitch or luggage tag configuration. The tails of the suture are then loaded into the anchor extra-articularly, and the anchor is then implanted into the glenoid securing the construct (Fig. 23.3).

Care was taken to not over-plicate the posterior capsule during repair in order to prevent postoperative stiffness and the risk of decreased sports performance in this overhead athlete. For contact or collision athletes with posterior instability, dislocation, or subluxation, it may be more desirable to achieve capsular plication in addition to labral re-fixation.

Postop Recovery

Our standard posterior labral rehabilitation protocol was followed (Table 23.1). The patient wore a padded sling with abduction pillow for the first 6 weeks postop. Full elbow and wrist ROM were maintained throughout recovery. Postoperative passive ROM exercises were started on postop day 3 and continued for 4 weeks, after which active-assisted ROM

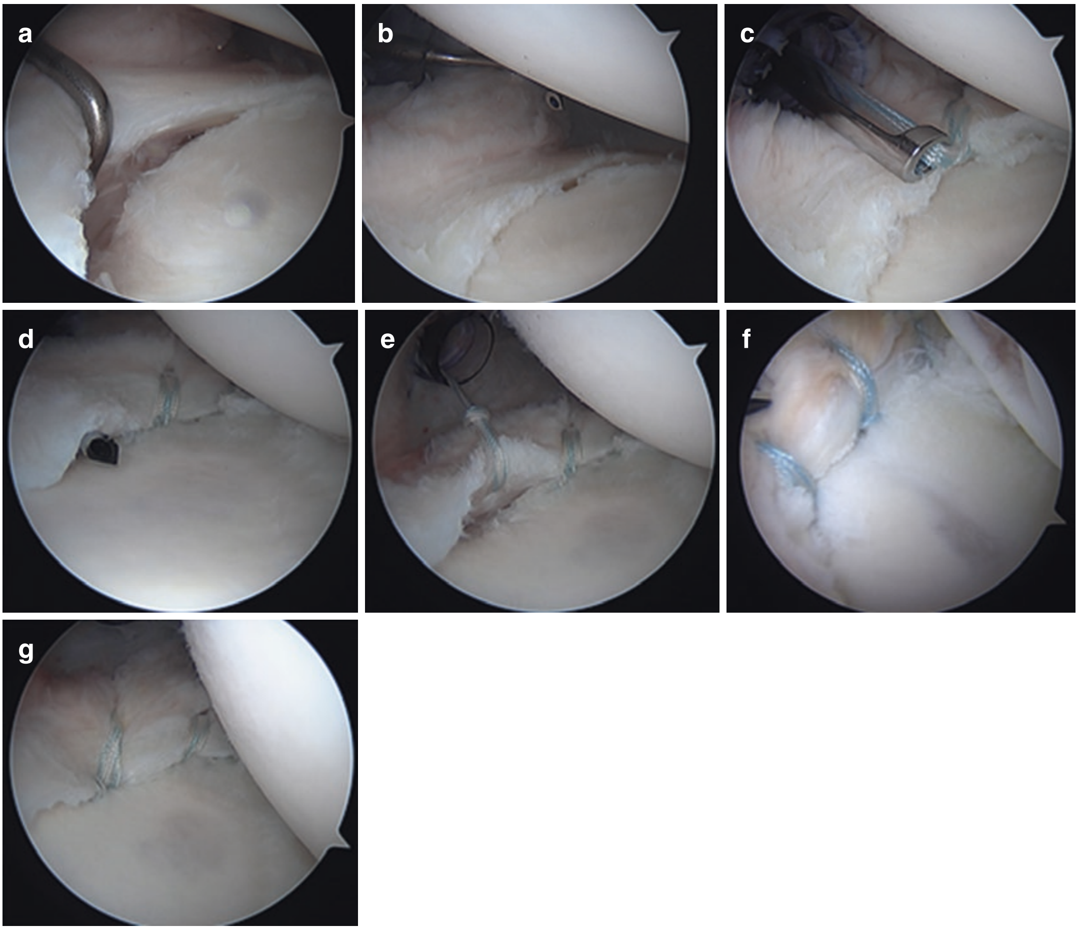

Fig. 23.3 Arthroscopic posterior labrum repair. (**a**) Arthroscopic view after posterior labrum mobilization demonstrating a large posterior labrum tear. (**b**) A suture shuttle device like the one pictured can facilitate passage of the suture through/around the labrum and capsule. (**c**) A knot pusher is used to secure the "cinch" stitch around the labrum. (**d**) Sequential placement of anchors proceeds from an inferior to superior direction. (**e**) Demonstration of the labrum "cinch" stitch prior to anchor placement and re-fixation. (**f**) The completed repair. (**g**) A similar repair in a collision athlete with an osteochondral lesion of the posterior humeral head from a traumatic etiology

exercises were started. At her 4-week postop visit, her shoulder could passively flex 110° and externally rotate 30°. At 8 weeks postop, she could actively flex to 140° and externally rotate to 45°. At this point, full active ROM exercises were started. At 12 weeks postop, rotator cuff and periscapular muscle strengthening exercises were started and advanced by her athletic trainer. At 4 months postop, she started an 8-week interval overhead volleyball training program. After the conclusion of this program, she returned to full volleyball activities (approximately 6 months post-surgery).

Outcomes

At her 1-year follow-up, she reports that she is able to serve, set, and spike at full strength, without pain. She has symmetric and full ROM with 5/5 strength bilaterally.

Summary

Posterior instability can be more difficult to diagnose than other forms of instability. It can occur following an acute traumatic event, such as dislo-

Table 23.1 Brief postoperative rehabilitation protocol

Postoperative time range	Range of motion	Strengthening	Additional comments
0–1 weeks	Active ROM of the elbow, wrist, and hand Passive forward flexion and abduction in the scapular plane to 90°	None	Arm is kept in sling with abduction pillow as much as possible Cryotherapy is used for first week
2–4 weeks	Outpatient physical therapy is begun. Passive ROM is begun in all planes	None	Arm is not internally rotated or adducted past the midline Avoid stretching of the posterior capsule
4–8 weeks	Active-assisted range of motion. Full internal rotation allowed at week 6		Sling is discontinued at 6 weeks
8–12 weeks	Full active ROM Posterior capsule stretching is begun	When 80% active ROM is achieved, deltoid, rotator cuff, and periscapular muscle strength training is begun. Training is advanced based on patient tolerance and ability	
>12 weeks	Full active ROM	Continue strength training	Sport-specific rehab is begun when the patient has achieved 80% strength (4–6 months post-op) Return to play for non-throwers 6 months Return to play for throwers 9–12 months

cation; however, it can also occur due to repetitive microtrauma caused by high-force overhead activity. Similarly, while patients may report instability or subluxation, some patients may only report deep shoulder pain and discomfort. Therefore, any overhead athlete that reports consistent shoulder pain and diminished strength should be evaluated for an instability injury. Physical exam can effectively narrow the differential diagnosis. A large paralabral cyst may lead to suprascapular nerve compression and periscapular atrophy. However, atrophy of other muscles, scapula winging, or sensation changes warrant an in-depth neurological work-up.

ROM and strength are often normal with posterior instability; however, pain with the arm in flexion, adduction, and internal rotation is an indicator of posterior instability. While the sensitivities of provocative physical exam maneuvers are limited, they are highly specific and can be useful in identifying the cause of patients' symptoms [9, 10]. High-resolution MRI arthrography is the gold standard for instability diagnosis and should be obtained preoperatively in all patients considering surgical intervention [7]. In patients presenting after acute dislocation, contrast may not be needed due to the presence of hemarthrosis [4]. Contrast was indicated in our patient due to the chronicity of symptoms without a clear-cut injury mechanism.

Conservative management is often unsuccessful in highly skilled athletes, patients with large tears, or patients with osseous injury. Physical therapy focuses on strengthening the rotator cuff muscles and scapular stabilizers and training-coordinated, synchronous scapulohumeral movements. Consideration must be given to the timing of interventions. Conservative treatments may be prolonged or transitioned early to surgical intervention based on the athlete's season and individual needs. Arthroscopic stabilization is the preferred surgical method for intervention. Strict adherence to postop recovery procedures and the use of an interval training program (throwing, hitting, etc.) may decrease the likelihood of repair failure and ease transition into full sport activity.

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24

A 24-Year-Old Thrower: First Time Dislocation Sliding into Second Base

Scott LaValva, Ann Marie Kelly, M. Patrick Kelly,
and John D. Kelly IV

A 24-year-old AAA minor league pitcher was sliding headfirst into the second base on a steal attempt and while diving to tag the base suffered a first-time anterior shoulder dislocation. His arm was noted to be approximately 20° of abduction and in hyperextension. The athletic trainer noted the injury and promptly alerted the covering physician who was not able to reduce the arm applying traction after administration of ½ % lidocaine intra-articularly. He was taken to the emergency room, where after conscious sedation, the shoulder was reduced, approximately 4 hours post injury.

The patient was given a sling and told to see the team physician the following day. He was found to be neurovascular intact.

He presented to the physician's office whereupon radiographs were obtained of the affected shoulder including an AP in external rotation (Fig. 24.1), AP in internal rotation (Fig. 24.2), as well as axillary view. A small Hill-Sachs lesion as well as subtle glenoid bone loss was noted.

Fig. 24.1 AP in external rotation showing subtle signs of Hill-Sachs lesion and loss of anterior glenoid contour

After confirming that there were no obvious neurologic deficits, the patient was told to continue sling wear only as comfort dictated and encouraged to perform gentle range of motion exercises to tolerance.

An MRI was obtained 2 days later which showed a significant Hill-Sachs lesion with minimal glenoid bone loss as well as anterior labral disruption (Figs. 24.3 and 24.4).

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Fig. 24.2 AP in internal rotation demonstrating Hill-Sachs lesion

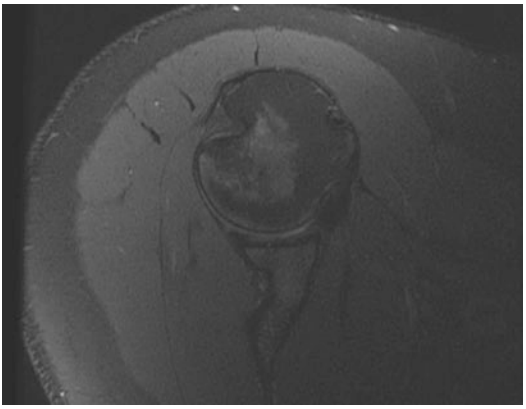

Fig. 24.3 T2 axial MRI image demonstrating Hill-Sachs lesion

Importance of Imaging

The presence of bone defects after anterior instability adversely affects the success of nonoperative care and increases recurrence rate after surgery [1]. The presence of anterior glenoid bone loss over 13% has been shown to be particularly consequential in predicting patient satisfaction after solely soft tissue repair (Bankart) [2]. Hill-Sachs lesions, especially those that fall medial to the "glenoid track" or region where the glenoid articulates the humeral head, will predictably engage in abduction external rotation and lead to appreciably greater recurrence rates after soft tissue repair (Bankart) alone [3].

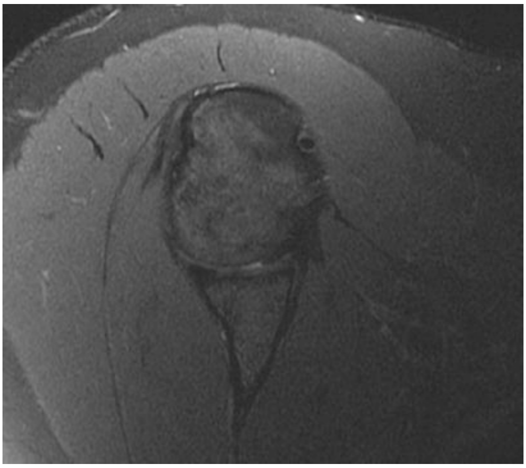

Fig. 24.4 More distal axial T2 MRI image portraying subtle anterior glenoid bone loss and anterior labral tear

Our patient had minimal glenoid bone loss but had a Hill-Sachs lesion of approximately 25 mm in width. This would place the patient at a higher risk of "engagement" in abduction – external rotation – throwing position.

Evaluation

The patient returned in 2 weeks feeling much more comfortable but demonstrated limited range of motion and deficits in strength for both deltoid and spinati. He was sent to formal physical therapy for dedicated cuff and scapular strengthening exercises. He underwent a full kinetic chain evaluation as well.

Ten weeks subsequently, he returned and stated he had attempted to throw but had significant posterior shoulder pain during late cocking.

At this point, exam findings were normal cuff strength, no evidence of scapular dyskinesis, and a completely normal neurovascular exam. On the affected throwing arm, he demonstrated 10° of increased external rotation as compared to the contralateral arm and a loss of 15° of internal rotation. His relocation test [4] was positive although he did not demonstrate any signs of apprehension.

Significance of Exam Findings

The patient demonstrated signs of persistent anterior instability. Relocation positivity is seen in the presence of internal impingement and anterior laxity [4, 5]. Although he did not demonstrate apprehension, it is likely that the Hill-Sachs lesion in this patient was truly "engaging" due to the extreme degree of external rotation the throwing motion demands [6]. In addition, the presence of even smaller Hill-Sachs lesions can appreciably compromise shoulder stability [7].

Treatment

A lengthy discussion with the patient ensued, and he recognized that his shoulder in its current state would not afford him the ability to play at any reasonably competitive level. He was apprised of the likely possibility that he would lose appreciable range of motion after surgery and that his pitching career was indeed in jeopardy. He consented to an arthroscopic evaluation with possible stabilization.

An arthroscopic Bankart procedure was proposed to the patient with the possibility of a *remplissage* or "filling" of the Hill-Sachs lesion [8]. The patient was advised that the rehabilitation course would be protracted, and he was further reminded that his pitching career was uncertain.

Surgery

The patient was brought to the OR and placed in lateral decubitus position with the arm in 45° abduction and external rotation (Fig. 24.5).

A standard posterior viewing portal was made, and diagnostic arthroscopy revealed the presence of a Bankart lesion which extended from the 2 o'clock to 6 o'clock position (Fig. 24.6).

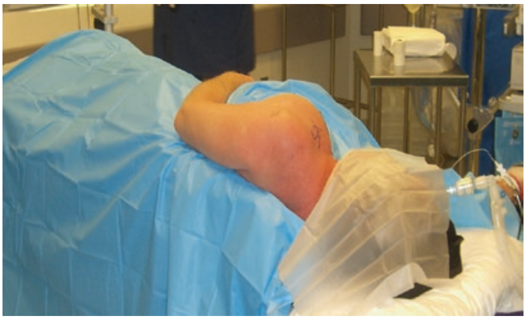

Fig. 24.5 Lateral decubitus position

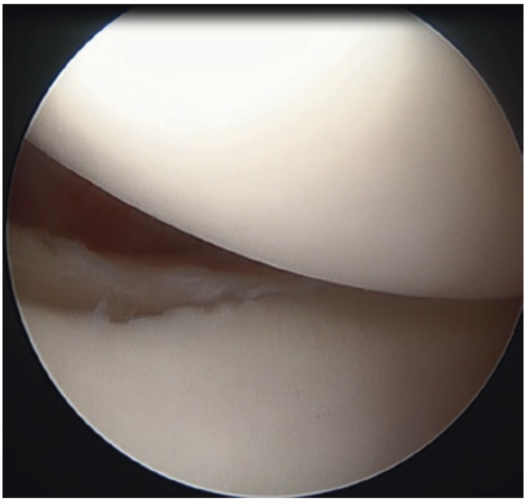

Fig. 24.6 Bankart lesion

A Hill-Sachs lesion was found on the posterolateral humeral head which was found to "engage" the anterior glenoid rim in abduction and extreme external rotation.

While viewing from a high anterolateral (AL) portal and working through a standard anterior portal, the labral tear was prepared for fixation by liberating soft tissue off the glenoid until the subscapularis fibers were visualized. Care was taken to free labral tissue down beyond the 6 o'clock position inferiorly.

Before labral repair the humeral head defect was prepared for remplissage. While viewing from the high AL portal, the lesion was roughened with a shaver, and a small awl was used to punch several holes into the lesion to promote bone marrow egress (Fig. 24.7). A standard rota-

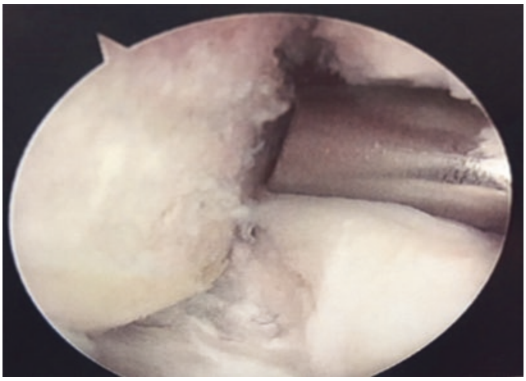

Fig. 24.7 Hill-Sachs lesion as viewed from anterior superior portal

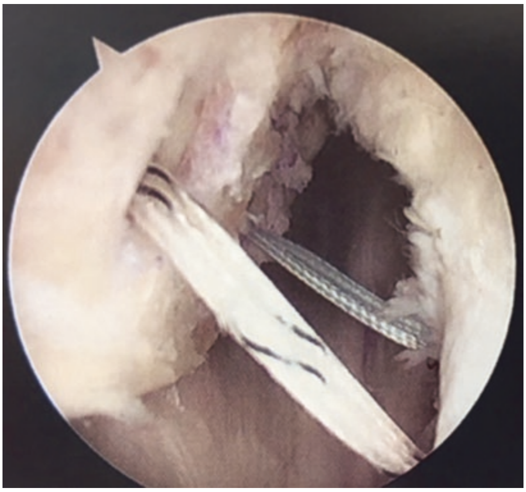

Fig. 24.8 Anchors placed in Hill-Sachs lesion

tor cuff anchor was placed into the distal-most aspect of the lesion through the posterior portal. It was felt that two anchors would be necessary to prevent engagement, so a more proximal anchor was placed through the same portal (Fig. 24.8).

A more posterior lateral portal was created, and a cannula was inserted into the subacromial space so that infraspinatus tendon – not muscle – would be incorporated into the remplissage construct. This “safe zone” not only ensures the purchase of more robust tendinous tissue but also will theoretically cause less restriction of motion [9]. The distal anchor sutures were retrieved first with the cannula resting in the subacromial space while visualizing the intra-articular space. Through the same cannula, the more proximal anchor suture limbs were captured. The distal-most sutures were tied first, with a posterior directed force applied to the humeral head as a means of facilitating joint reduction. Subsequently the proximal sutures were tied, and excellent approximation of the infraspinatus to the lesion was seen (Fig. 24.9).

Fig. 24.9 “Filled” Hill-Sachs defect

Subsequent to remplissage, the anterior labral tissue was reapproximated to the anterior glenoid rim using two suture anchors (Fig. 24.10). Horizontal mattress configuration was used, and great care was undertaken to ensure that only a modest capsular shift was executed in order to avert excessive motion loss in the abducted external rotation position [10]. In addition, only labral tissue was opposed in the proximal two anchors so that no rotator interval tightening would result [11].

Rehab

The patient wore a sling for 5 weeks but was instructed on immediate scapular retraction exercises in addition to wrist and elbow motion as well. Formal therapy was instituted at week 6 with an emphasis on range of motion (ROM) and scapular strengthening. Rotator cuff strengthen-

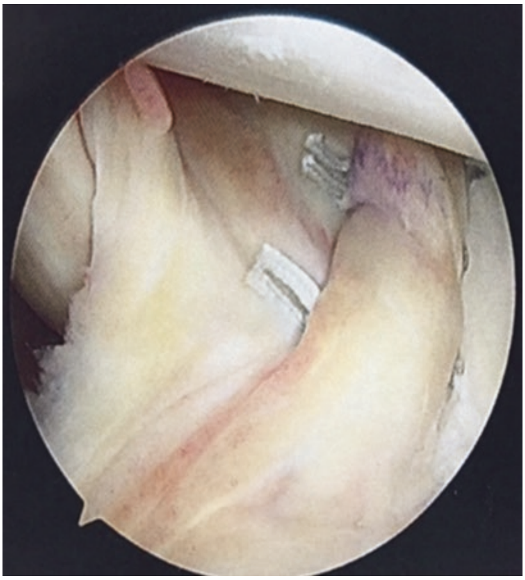

Fig. 24.10 Anterior "bumper" restored with horizontal mattress suture

ing was withheld until post-op week 8 in order to protect the remplissage. Posterior capsular stretching as well as addressing of core and kinetic chain deficits was emphasized throughout the rehabilitation period.

The patient slowly regained near full ROM and ultimately demonstrated 10° more external rotation on the dominant (r) arm as compared to the left with no signs of apprehension or relocation. An interval throwing program was commenced at week 12 with light tossing advancing to 75% throwing speed at month 5. At 7 months he was advanced to mound throwing full speed and was clocked at 91 mph as compared to 95 mph pre-injury. He ultimately returned to AA ball and was enjoying appreciable playing time as a relief pitcher.

Discussion

The treatment of the overhead athlete who sustains an anterior instability event is fraught with challenges. The act of late cocking, abduction, and external rotation is precisely the same position where anterior instability is most commonly experienced [12]. Thus, treatment of anterior instability must be treated very precisely with anatomic restoration of the labral bumper and re-tensioning anterior capsular tissue without over constraint [13, 14].

In addressing labral tears in the overhead athletes, it is imperative not to over tension the capsule and merely restore native anatomy. While some capsular laxity is inherently present, a small purchase of the inferior glenohumeral and middle glenohumeral ligaments (IGHL, MGHL, respectively) must be undertaken during labral refixation. Furthermore, the procedure was undertaken with the humerus in slight external rotation during traction, another measure employed to avoid over constraint.

The glenoid track [15] concept has aided surgeons in more precisely treating bone defects associated with anterior instability. Engagement of a Hill-Sachs lesion can be predicted in the ABER position based on the width of glenoid defect and size and location of the Hill-Sachs lesion [15]. However, in throwers, extreme degrees of external rotation are necessary to propel a fast ball over 90 mph [16]. Thus a Hill-Sachs lesion in throwers is much more likely to "engage" due to the extreme rotational movement of the humerus in late cocking. Thus the humeral defect was treated with remplissage, a procedure with verified success in addressing anterior instability [17, 18]. In addition, remplissage has not been associated with any appreciable loss of motion which qualifies it as a reasonable option for overhead athletes [19].

It is paramount to counsel patients with a truthful overview of expected results. Essentially all patients who undergo anterior instability surgery will lose appreciable external rotation [20]. Thus, some velocity will be predictably lost. Our patient understood the risks of surgery but recognized that the instability of his injured shoulder would not permit even light overhead throwing. His return with diminished velocity is a predictable consequence of loss of external rotation.

Arthroscopic treatment is the preferred approach to overhead athletes in that the labrum and capsular tension can be more precisely restored and morbidity associated with open surgery (stiffness, subscapularis injury, scarring) can be averted [21, 22].

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25

A 25-Year-Old Recreational Softball Athlete with Internal Impingement

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History

A 25-year-old female presented with chronic right shoulder pain, localized to the posterosuperior aspect, for the past 7–8 years. She was a college softball athlete that had persistent symptoms throughout her career. She is not a pitcher but experiences these symptoms during long throws across the field. She currently continues to play sports recreationally. Previously, she has failed conservative management for her symptoms through physical therapy, massage, activity modification, and anti-inflammatories. She has not previously had any injections for her symptoms. The patient wishes to continue to play softball recreationally without hindrance from her symptoms.

Initial suspicion of internal impingement begins with the presentation of the overhead athlete with chronic shoulder pain, often in the posterior-superior shoulder. Such athletes place consistent stress on the posterior aspect of the glenohumeral joint. Classically, the patient will present with discrete stages of symptoms [1]. When presenting early, the patient will complain of stiffness and the need for longer warm-ups. Next, the patient will localize the pain to the posterior aspect of the joint only during the pitching motion, though there is no pain with normal activity. The final stage is non-refractory to normal activity. Our softball athlete complains of chronic posterior-sided shoulder pain that is refractory to conservative treatment.

Physical Exam

On physical exam, the patient was healthy appearing, of normal body habitus, and in no acute distress. No deformity of the scapula was appreciated when viewing from behind. Scapular movement was normal throughout forward flexion and abduction with no evidence of dyskinesia. Her cervical range of motion was maintained with no evidence of neck discomfort. Though she had full range of motion, she experienced pain with abduction and external rotation and felt her symptoms reproduced with abduction and external rotation. She was found to have a positive O'Brien's sign and positive anterior apprehension. She experienced mild anterior pain near the biceps, although palpation did not directly reproduce her symptoms. There was no pain over the

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acromioclavicular or sternoclavicular joints. Strength was maintained in elevation and rotation. Belly press test and lift-off test were negative.

Careful examination is required, particularly of the throwing shoulder. Several relevant anatomical abnormalities may be noted of the throwing shoulder such as increased musculature and glenohumeral internal rotation deficit. The scapulae must be inspected for evidence of winging, dyskinesis, or prominence of the inferomedial border. Tenderness to palpation should be evaluated at the coracoid process, glenohumeral joint lines, biceps tendon, acromioclavicular joint, and deltoid for alternative pathologies related to pitching.

Range of motion must be evaluated to determine whether there is a shift in the rotational arc to allow for reduced internal rotation and increased external rotation. Glenohumeral internal rotation deficit is often a result of posterior capsular contracture present in internal impingement [2, 3]. It is important to evaluate the rotator cuff as impingement of the posterosuperior supraspinatus or infraspinatus may result in partial articular-sided tears or fraying resulting in pain with resisted cuff testing.

The relocation test places the arm in 90° of abduction and maximal external rotation. After which, posterior load on to the humerus results in pain, while anterior load results in relief of pain [1]. Similarly, the posterior impingement sign involves placing the shoulder in 90–110° of abduction with maximal external rotation. Eliciting pain within this position is correlated with tears/fraying of the posterior labrum or articular side of the rotator cuff [4]. General instability must also be evaluated for adaptive laxity associated with the throwing athlete.

Imaging

Radiographs were taken to assess osseous anatomy at initial patient visit. Four views of the shoulder were ordered, including the AP, axillary, Y-view, and Stryker's view. Radiographs were negative for fractures and dislocation. No Bennett's lesion was observed on axial view. The glenohumeral joint and acromioclavicular joint appeared normal (Fig. 25.1).

Reproduction of pain with abduction and external rotation with the patient's history as a throwing athlete indicates high suspicion for internal impingement. Given sufficient evidence in support of this diagnosis, MRI was indicated as the next modality chosen to demonstrate soft tissue irregularities within the shoulder joint, particularly the posterior labrum and rotator cuff. The supraspinatus, subscapularis, and infraspinatus were noted to be intact. There was evidence of diffuse labral pathology, particularly superiorly with some extensions anteriorly (Fig. 25.2). An ABER view can be used to evaluate the area of contact between the posterior-superior rotator cuff and labrum with improved visualization of undersurface rotator cuff tears.

Diagnosis

This patient presents with advanced symptoms associated with internal impingement. Given the fact that she is experiencing chronic posterior shoulder pain and her history as a long-term collegiate softball athlete, the index of suspicion is very high for internal impingement and associated pathology. On physical exam, this diagnosis was supported by positive relocation test, pain with abduction-rotation testing, and posterior impingement signs. Finally, our diagnosis was confirmed on MRI, which indicates diffuse fraying of the posterior labrum. Additional diagnoses that must be excluded include PASTA and PAINT lesions if symptoms persist after treatment.

Intervention/Rehabilitation

The majority of patients can be managed nonoperatively, in the form of rest, activity modification, and rehabilitation. Continued exertion through the throwing will continue to exacerbate symptoms, so adequate rest from this motion will allow the patient to recover during rehabilitation. Initial evaluation includes adequate visualization of scapular motion and correction of any

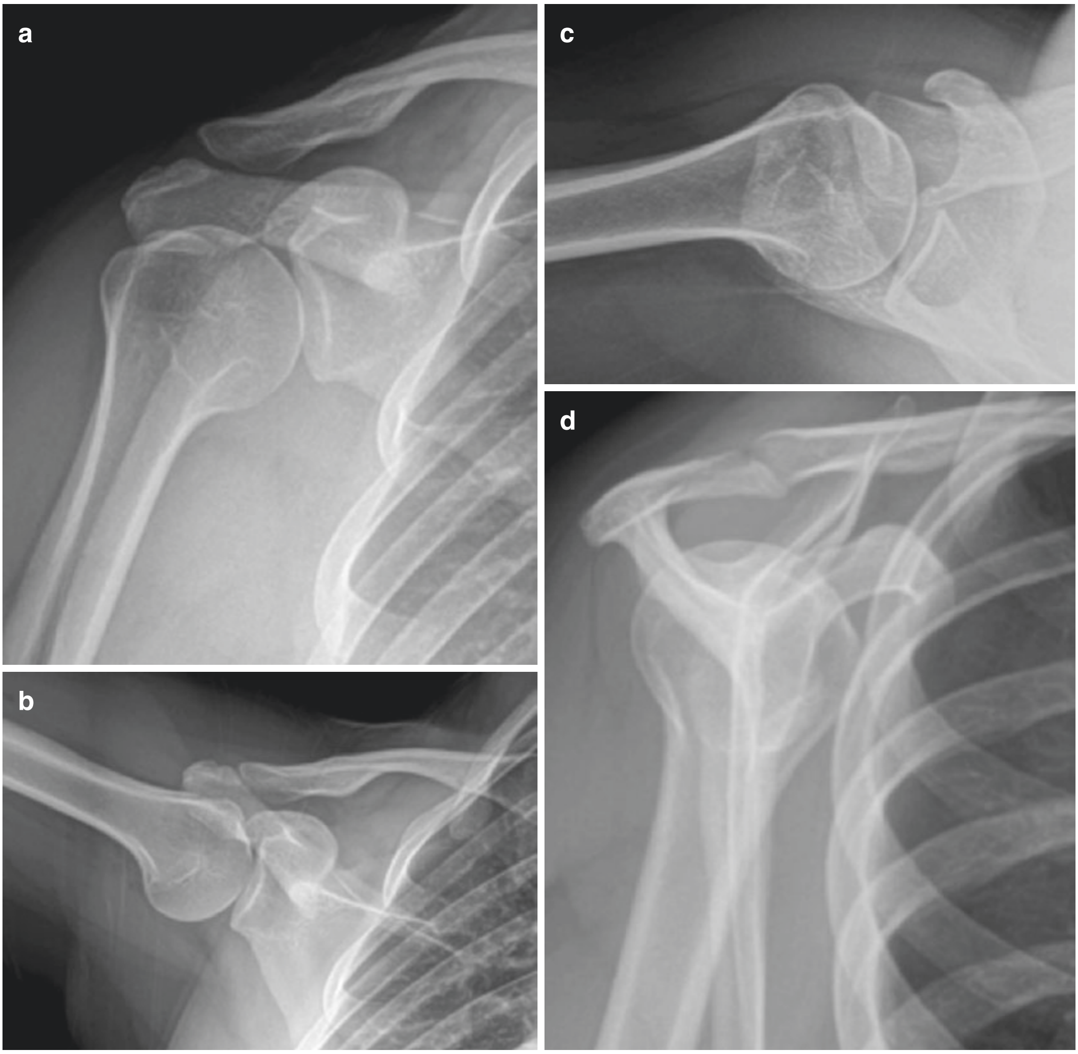

Fig. 25.1 Shoulder series demonstrating normal glenohumeral and acromioclavicular joint. (**a**) AP shoulder with neutral rotation, (**b**) shoulder Stryker's view, (**c**) shoulder axillary view, (**d**) shoulder Y-view

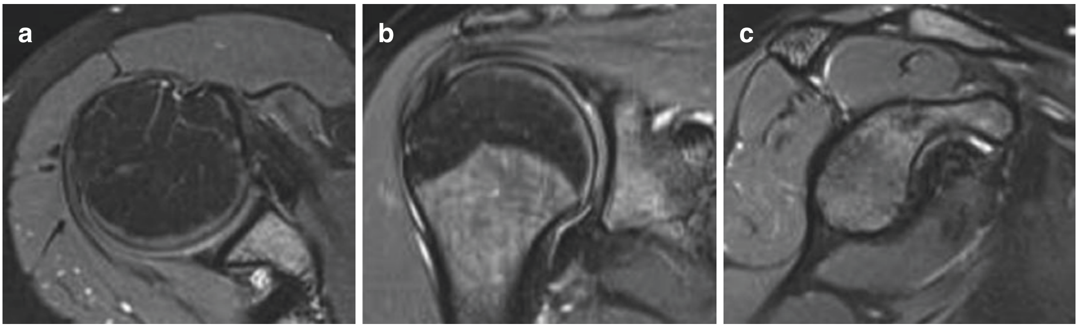

Fig. 25.2 Diffuse pathology of the superior aspect of the glenoid labrum with extension into the anterior portion. (**a**) axial, (**b**) coronal, (**c**) sagittal

dyskinesia. In addition core strength should be assessed and deficiencies should be addressed. Rehabilitation of the shoulder may be performed by strengthening the rotator cuff muscles and stretching the posterior capsule. Restoration of pain-free baseline motion is required before return to any throwing activity. The sleeper stretch is the most common method of stretching the posteroinferior capsule. The patient lies down on the ipsilateral side with the shoulder flexed and elbow at 90°. The shoulder is then passively internally rotated by the contralateral arm toward the table. An interval training program involves four phases of rehabilitation: acute phase, intermediate phase, strengthening phase, and return-to-throwing phase [5]. This program allows the patient to progress slowly over 6–12 weeks. Recurrent symptoms are treated by increasing rest and returning to a previous phase. Coaches and trainers should also pay close attention to correct poor throwing form and monitor pitch counts before and after rehabilitation. Additionally, pain may be managed with nonsteroidal anti-inflammatory drugs, injection, ice, iontophoresis, and heat.

Decision was made to perform elective posterior labral repair due to chronic symptoms over 7–8 years that were recalcitrant to conservative therapy. Patient was placed in lateral decubitus position using an inflatable beanbag positioning device. Lateral arm distraction device is used to optimize visualization (SPIDER2, Smith & Nephew, Andover, MA, USA). A dynamic examination can be performed bringing the arm out of traction, and with the scope in the posterior portal, evaluating for labral peel back or internal impingement during abduction-rotation maneuvers (Fig. 25.3).

Diagnostic arthroscopy when viewing from the posterior portal revealed large posterior labral tear accompanied with fraying (Fig. 25.4). The decision was made to perform debride fraying tissue and prepare the posterior labrum for repair.

Using an anterosuperior viewing portal and posterior working portal, the labrum was debrided to remove the frayed edges. This was performed using an arthroscopic shaver. Following debridement, an arthroscopic elevator was used to raise the capsulolabral complex above the glenoid in order to facilitate repair (Fig. 25.5).

A 7 o'clock portal was established to achieve adequate trajectory of suture anchors. Two knotless suture anchors (PushLock, Arthrex, Naples, FL, USA) with suture tape were used to repair the capsulolabral complex. Suture tape was shuttled using a left-sided arthroscopic crescent with loaded nitinol. Following repair, the undersurface of the rotator cuff was found to be intact, and the long head of the biceps tendon did not demonstrate any signs of inflammation or dislocation (Fig. 25.6).

Rehabilitation

0–4 weeks:

- Maintain in abduction or external rotation sling.
- Focus on grip strength and elbow/wrist/hand ROM.
- Codman's exercises to prevent excessive shoulder stiffness.

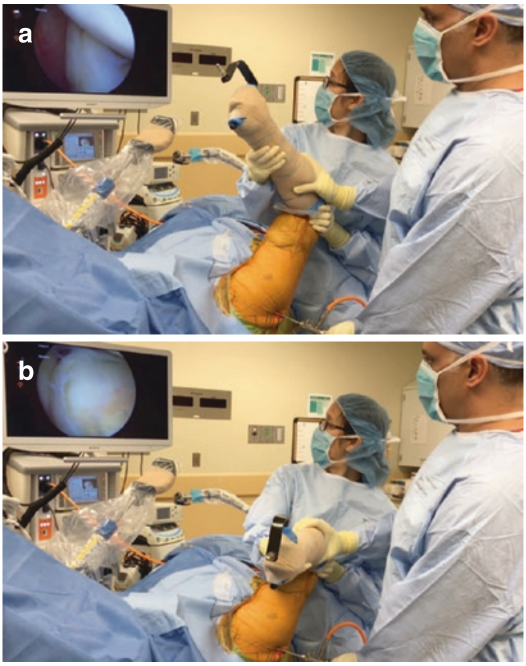

Fig. 25.3 Dynamic evaluation of internal impingement when viewing from a standard posterior portal in (**a**) abduction and neutral rotation and (**b**) abduction and external rotation demonstrating a "peel-back" of the labrum

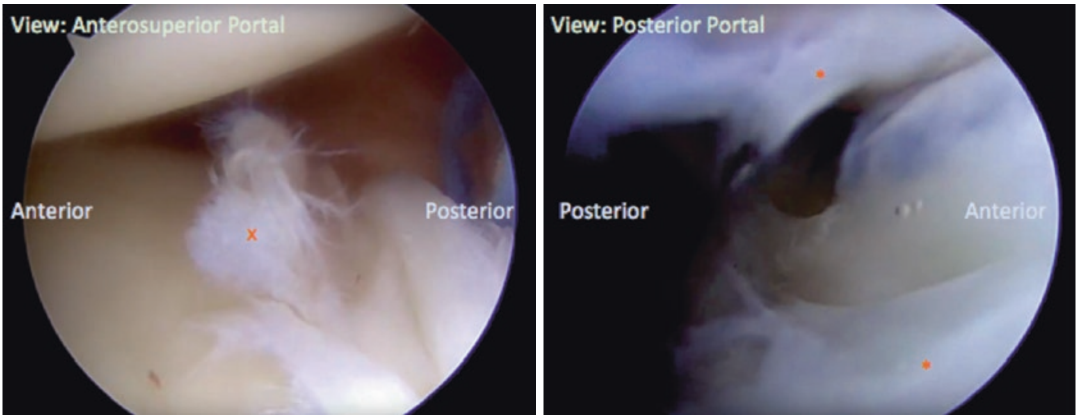

Fig. 25.4 Demonstration of pathoanatomy during diagnostic arthroscopy; x, fraying of posterior labrum; *, large labral fracture

Fig. 25.5 Appropriate debridement of the labral pathology. (**a**) Trimming the frayed labrum, (**b**) following trimming, (**c**) elevation of the capsulolabral complex over the glenoid

Fig. 25.6 Surgical technique for labral repair. (**a**) Double-loaded suture anchors were placed in posterior labrum using the 7 o'clock portal; (**b**) suture passer loaded with nitinol was used to shuttle sutures before tying; (**c**) final repaired labrum

4–6 weeks:

- Discontinue sling.
- Begin passive range of motion, assisted active range of motion, and active range of motion.
- Internal rotation to stomach.
- Restrictions from cross-body adduction and manipulation by therapist.
- Begin strengthening of scapular stabilizers.

- Begin isometric exercises with arm at side – deltoid, scapular, and ER/IR with arm at side (submaximal).

6–12 weeks:

- Increase ROM to within 20° of opposite shoulder.
- Encourage daily ROM rehabilitation and continue isometrics.
- Advance strengthening as tolerated; limit three times per week to avoid rotator cuff tendinitis.

3–12 months:

- Full, painless ROM.
- Sport-specific rehab at 3 months, including advanced conditioning.
- Return to throwing at 4½ months.
- Throw from pitcher's mound at 6 months.
- MMI at 12 months.

Post-op/Return to Sport

The patient endorsed persisting symptoms of recurrent instability and pain at 6-week follow-up. Precautionary MRI revealed no new pathology. Aggressive physical therapy was advanced. On 3-month clinic visit, the patient reported complete relief of symptoms: no recurrent instability and no pain. At this visit, the patient was noted to be stiff. She had 60° of external rotation and internal rotation to midthoracic level. At 6 months postoperatively, she has progressed sport-specific therapy. Once full range of motion has been achieved, particularly in regard to external rotation, throwing can be initiated. Expected return to full throwing occurs at 8–12 months following surgery.

Outcomes

The present case demonstrated classic symptoms of internal impingement. This patient was found to have posterior labral pathology that inhibited her ability to participate in recreational sport. Given her long history as an overhead athlete, she had a strong desire to play without hindrance of her shoulder. At roughly 6 months postoperatively, she was able to return to sport, though not at full capacity. From preoperatively to 6 months follow-up, her Kerlan-Jobe score improved from 29.01 to 59.91. This patient experienced near-complete relief of symptoms with activities of daily living. It is important to note that physiologic adaptations such as anterior laxity and posterior contracture remain. With capsular changes, it has been noted that the glenoid remodels such that the posterior aspect becomes more prominent.

Increasing literature on clinical outcomes is becoming available as zone-specific capsulolabral repair is being performed in the setting of internal impingement. Return to all sports has been reported between 68% and 90%, while return to pre-injury level of sport has been reported between 50% and 90%. In throwers, return to sport has been reported as 85%, while return to pre-injury level has been reported 48–56% [6–9]. The time to return to sport is reported to range from 3 to 18 months, while time to return to pre-injury level ranges between 6 and 18 months [10]. Additionally, McClincy and colleagues have demonstrated equivocal results between throwing and non-throwing athletes in regard to return to sport outcomes [7]. Glenohumeral retroversion is a common abnormality in pitching shoulders to balance associated humeral head retroversion. Though this has been implicated in increasing the incidence of atraumatic posterior shoulder instability, there is no indication that this may affect postoperative outcomes following capsulolabral repair [8].

Summary

The acceleration achieved from the overhead throw is a result of force funneled from the driving leg, trunk rotation, shoulder, and finally the ball [11, 12]. Rotational torque produced during the overhead throw to achieve this velocity places a great deal of stress on multiple areas of the shoulder that can lead to injury. Repetitive overhead throws result in osseous and capsular changes to allow for greater degrees of external rotation at the expense of deficit in internal rotation [2, 3]. The throwing athlete compounds these physiologic alterations during their career, and though they are predominantly asymptomatic, they are predisposed to specific injuries [11, 13–15]. These anatomic changes contribute in part to multiple incidences of shoulder injuries such as partial articular-sided rotator cuff tears, posterior labral or glenoid lesions, posterior capsular contracture, or a Bennett's lesion that will require operative management [2, 11, 16, 17]. The following is a case-based analysis that discusses anatomical changes and resulting management of a collegiate overhead athlete suffering from posterior shoulder pain as a result of repetitive throwing motion.

Anatomy and Physiology

Throwing velocity is proportional to greater degrees of external rotation [18]. Therefore, it is physiologically advantageous for the throwing athlete to shift the rotational arc [3, 19]. Several osseous and soft tissue changes occur to contribute to this shift in anatomy. The humeral head is initially retroverted at a mean of 78° in utero and derotates over time [20]. The rate of derotation is greatest between 6 and 12 years of age [20]. Retroversion of the humerus is a common finding in the throwing athlete to allow for greater amounts of external rotation [3]. The capsule is also implicated in the shift of the rotational arc. The posterior capsule becomes hypertrophied and scarred, which may sometimes be evidenced by the Bennett's lesion – an exostosis of the posteroinferior glenoid rim that results compounded microtrauma to the posterior band of the inferior glenohumeral ligament [17]. In compensation, the anterior capsule becomes lax and allows for greater external rotation at abduction [21]. Laxity of the rotator interval and coracohumeral ligament may also aid in achieving this rotational arc. In severe cases, this is manifested by the sulcus sign, with skin dimpling below the acromion upon inferior traction of the humerus. These physiologic adaptations allow for supraphysiologic external rotation of greater than 20°, at the expense of an equivalent glenohumeral internal rotation deficit (GIRD).

Mechanics of Injury

During arm cocking in abduction and maximal external rotation, several anatomic structures are vulnerable. In this position, the posterolateral aspect of the supraspinatus is pinched between the posterosuperior glenoid and posterolateral portion of the greater tuberosity (Fig. 25.7). Continued contact and compression may lead to damage to both the posterior labrum and supraspinatus.

Internal impingement within this position is a common etiology for articular-sided rotator cuff tears (PASTA lesion) within this population that is a result of friction between the undersurface of the supraspinatus and greater tuberosity of the humerus [16, 22]. Alternatively, the supraspinatus also twists through the overhead motion, resulting in tensile stress and stretch of the fibers that may contribute to PASTA lesions. Intratendinous lesions (PAINT lesions) may also be encountered by virtue of the same mechanism [23, 24].

The biceps tendon and superior labrum are increasingly recognized as a joint complex. The long head of the biceps tendon is thought to contribute to anterior instability of the glenohumeral joint [25]. During abduction-external rotation (ABER), the biceps tendon is externally rotated itself at its base, which causes excessive torsional forces on the biceps tendon as well as the superior labrum in a "peel-back" lesion.

Tightness of the posterior capsule results in contracture of the PIGHL and stretching of the anterior inferior glenohumeral ligament (IGHL). Excess repetition of these forces can lead to symptomatic anterior instability that will exacerbate internal impingement [26].

Conclusion

Internal impingement is a prevalent condition in the overhead athlete due to anatomical adaptations. In the overhead athlete presenting with

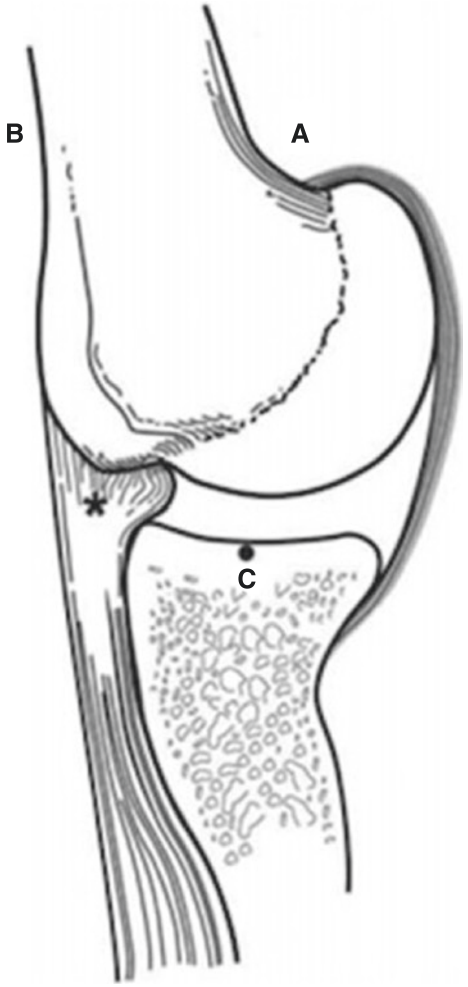

Fig. 25.7 Internal impingement in abduction-external rotation of the glenohumeral joint. (**a**) anterior, (**b**) posterior, (**c**) glenoid. (Reprinted with permission from Burkhart et al. [27])

posterior shoulder pain, a thorough clinical history and physical exam must be performed to rule out pathologies associated with internal impingement. Advanced diagnostic imaging is useful in confirming pathology. Many patients respond appropriately to conservative care which includes physical therapy, anti-inflammatories, injections, and rest from throwing. Patients recalcitrant to conservative therapy may likely benefit from arthroscopic procedures to relieve symptoms.

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26

A 27-Year-Old Thrower with Failed Labral Repair

W. Ben Kibler

History

A 27-year-old patient comes for evaluation and second opinion for chronic problems with his right dominant shoulder. He first experienced symptoms 5 years ago in his senior year of college noting soreness when throwing from the outfield. He was given some oral medication for the soreness and was able to complete the season. After college, he continued to play baseball in local adult leagues. He also was employed in a job that required frequent overhead lifting and loading. 2.5 years ago, while making a hard throw from the outfield, he experienced a sharp pain in the shoulder and was unable to throw overhand. He was diagnosed as having tendonitis and was told to rest for 3 weeks. He did not get better, could not throw, and was having difficulty raising his arm at work. He had a 6-week course of rehabilitation, with minimal improvement. His major limitations at that time were pain and weakness in abduction/external rotation, sharp pain upon throwing in the posterior shoulder on cocking to ball release, inability to perform repetitive overhead or pulling activities, and a feeling of a “dead arm” upon hard use in work or play. He had magnetic resonance imaging (MRI) and was diagnosed with a superior labrum anterior to posterior (SLAP) tear. He underwent arthroscopy and SLAP repair 16 months ago. The exact details of the repair were not known. He was held in a sling postoperatively for 3 weeks and then underwent 6 weeks of rehabilitation emphasizing joint range of motion and rotator cuff strength. He was allowed to resume overhead work and to start to throw 4 months postoperatively. He felt he was unable to achieve optimal status despite continuing rehabilitation. He felt he had the same limitations as before surgery and had more restriction of shoulder motion and decreased ability to achieve overhead positions. He could not play baseball and had to change his job at work. He felt his global rating of change (−3 significantly worse after treatment to +3 significantly better after treatment) was −3.

Clinical Examination

The lower body kinetic chain examination was normal with no signs of dynamic hip weakness, core weakness, and instability and had no loss of hip or lumbar range of motion. His scapular examination showed positive scapular dyskinesis with medial border prominence upon arm motion [1], with weakness in the low row maneuver and inability to voluntarily maximally retract the scapula on the thorax. He had a positive impingement sign with arm elevation above 110°, with relief by the scapular assistance test [2–4]. He

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had demonstrated weakness of external rotation at 0° and 90° of abduction and forward flexion at 90° which were made normal by the scapular retraction test [2, 5]. Glenohumeral internal rotation, external rotation, and total range of motion were 20°, 80°, and 100°, respectively, on the dominant side and 40°, 95°, and 135°, respectively, on the nondominant side. He demonstrated a positive modified dynamic labral shear test [6] with reproduction of his posterior shoulder symptoms and no relief by scapular retraction. He had a negative active compression test [7], negative Speed's test [8], and negative uppercut maneuver [6] for biceps injury. He had a negative anterior apprehension test [9] and negative sulcus sign [10]. The neurological examination was normal with no deficits noted.

Imaging

Plain radiographs were normal. MRI was ordered to evaluate the labrum. Contrast was used because of the increased ability to image the labrum, and a modification of the axial imaging sequence, called the oblique axial sequence, was used to better image the posterior labrum. Both the axial (Fig 26.1a) and oblique axial (Fig 26.1b) sequences demonstrated detachment and insubstance delamination in the entire posterior labrum. The posterior rotator cuff showed minimal articular-sided injury.

Comprehensive Diagnosis

The anatomic diagnosis is injury to the glenoid labrum, specifically the posterior component, from 10:00 down to 7:00 positions on the right shoulder. This was based on his history of chronic pain with an acute episode, posterior shoulder joint pain, especially in abduction/external rotation and the feeling of the "dead arm"; the posterior modified dynamic labral shear test, which has a high positive predictive value and likelihood ratio; and the positive imaging. These positive findings are necessary to determine that a labral injury exists and that it is significantly impacting the clinical symptoms [11]. The rotator cuff, biceps, and anterior ligamentous structures were not involved by clinical examination and imaging. Scapular dyskinesis and altered glenohumeral rotation were identified as deficits that impacted the clinical presentation and would need to be addressed in the postoperative treatment.

Treatment

Because of the lack of functional improvement and the positive clinical and imaging findings, arthroscopy with evaluation and revision labral surgery was recommended. The patient was counseled regarding the possible arthroscopic pathoanatomy, including labral injury, biceps pathology, rotator cuff injury, and articular cartilage injury, and that definitive surgical treatment would be based on the intraoperative findings. He was also counseled that the surgical objectives would include (1) adequate stabilization and repair of the entire posterior labrum; (2) restoration of tension in the posterior inferior glenohumeral ligament (PIGHL); (3) possible treatment of the rotator cuff and biceps pathology, if present; (4) improvement of the biceps excursion to increase glenohumeral external rotation; and (5) restoration of the bumper and washer function of the posterior labrum [12, 13].

At revision arthroscopy, the following findings were noted:

1. A single anchor with a high-tensile strength suture in a simple suture knot configuration had been placed at the 12:00 position at the base of the biceps (the suture was not taut) (Fig. 26.2).
2. The biceps had some inflammation at its base and was limited in rotational excursion with increased tension in glenohumeral external rotation. There was no intratendinous pathology and no outlet instability.
3. The labral injury extended from the 12:00 position down to the 7:00 position with detachment away from the glenoid from 12:00 to 8:00 and insubstance extension into the labrum down to 7:00 (Fig. 26.3).

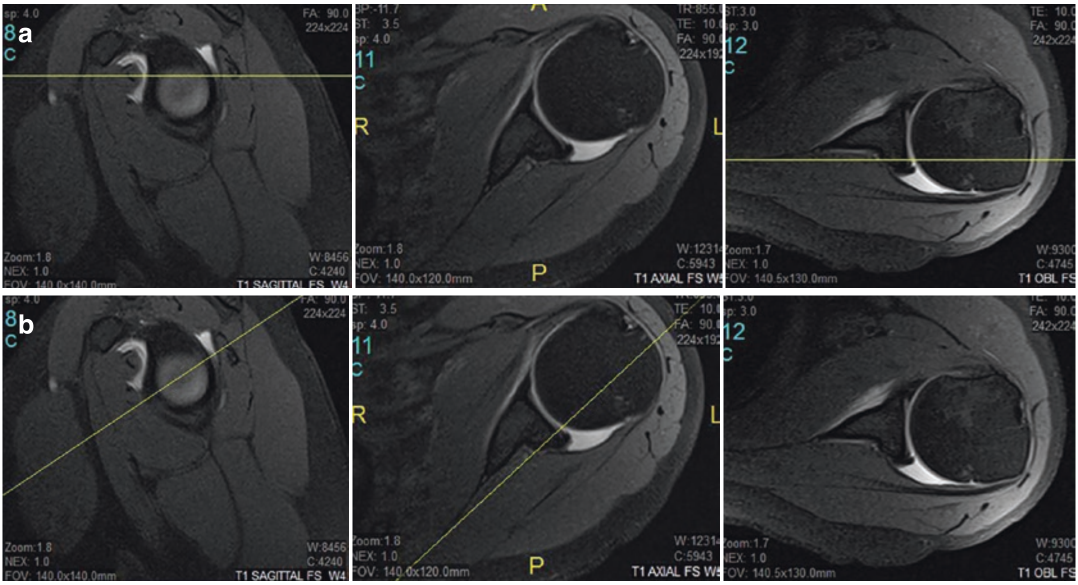

Fig. 26.1 Axial (**a**) and oblique (**b**) sequences demonstrating posterior labral injury

Fig. 26.2 Untaut simple suture knot configuration placed at the base of the biceps

4. Delamination of the posterior and superior labrum (Fig. 26.4).
5. Loss of tension in the PIGHL (Fig. 26.5).
6. Minimal (<10% depth) rotator cuff injury.
7. No articular cartilage injury.

Surgical treatment included (1) removal of the previous suture and mobilization of the base of the biceps; (2) mobilization and debridement of the posterior labral injury, including the insubstance injury; (3) abrasion of the glenoid rim; and (4) placement of anchors 7:30, 8:30, 9:30, and 11:00 with simple suture configuration to securely reattach the labrum, recreate the posterior bumper, re-tension the PIGHL (Fig. 26.6), and restore biceps excursion.

Postoperatively, the patient wore a sling for 3 weeks and followed previously published rehabilitation protocols [12, 14, 15]. During the initial 3 weeks, core strengthening exercises were instituted, and gentle scapular retraction was encouraged. At the beginning of week 4, closed chain and short lever arm exercises were used to regain motion and start strengthening. Because of the chronicity of the symptoms and the resulting inhibition of voluntary scapular control, specific retraining for scapular retraction was instituted [16]. At 6 weeks, he started overhead motion, maintained glenohumeral internal and external rotation exercises, and started gentle resistance training. At 3 months, he began open chain weights and return to work activities. At 4 months, he was started on a return-to-throwing program and allowed to bat. At 6 months, glenohumeral internal rotation, external rotation, and total range of motion were 30°, 95°, and 125°, respectively, on the dominant side and 40°, 100°, and 140°, respectively, on the nondominant side. Scapular dyskinesis was not present with symmetrical low row strength and improvement in

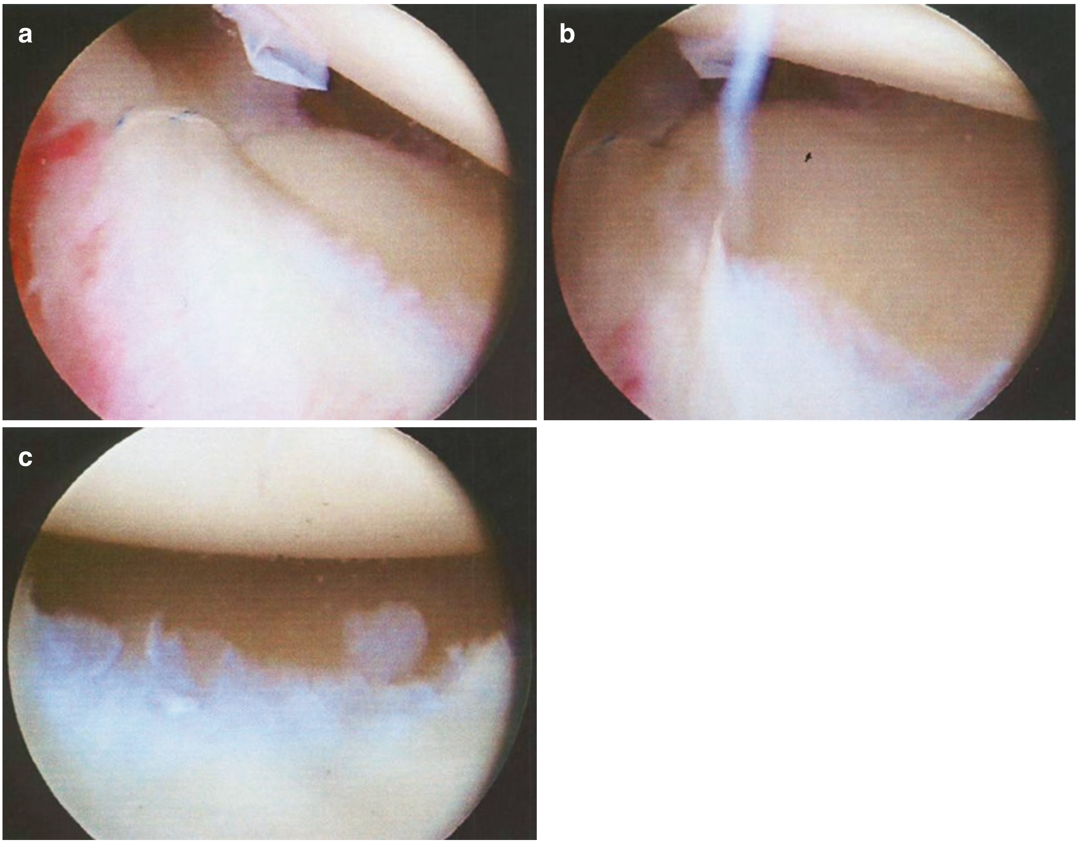

Fig. 26.3 Labral injury from the 12:00 position down to the 7:00 position (**a**) with detachment away from the glenoid from 12:00 to 8:00 (**b**) and insubstance extension into the labrum down to 7:00 (**c**)

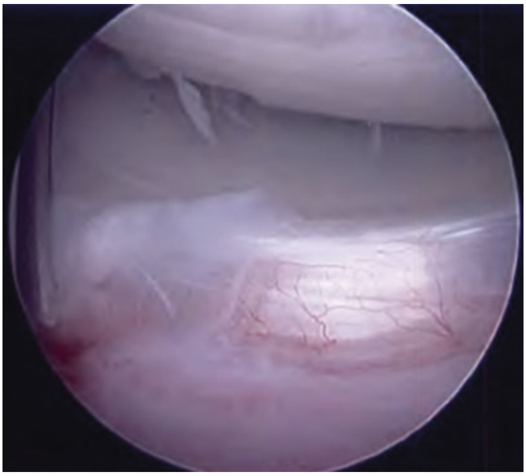

Fig. 26.4 Delamination of the posterior and superior labrum

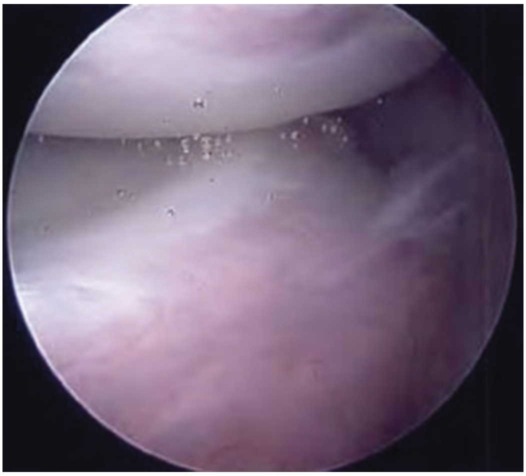

Fig. 26.5 Loss of tension in the PIGHL

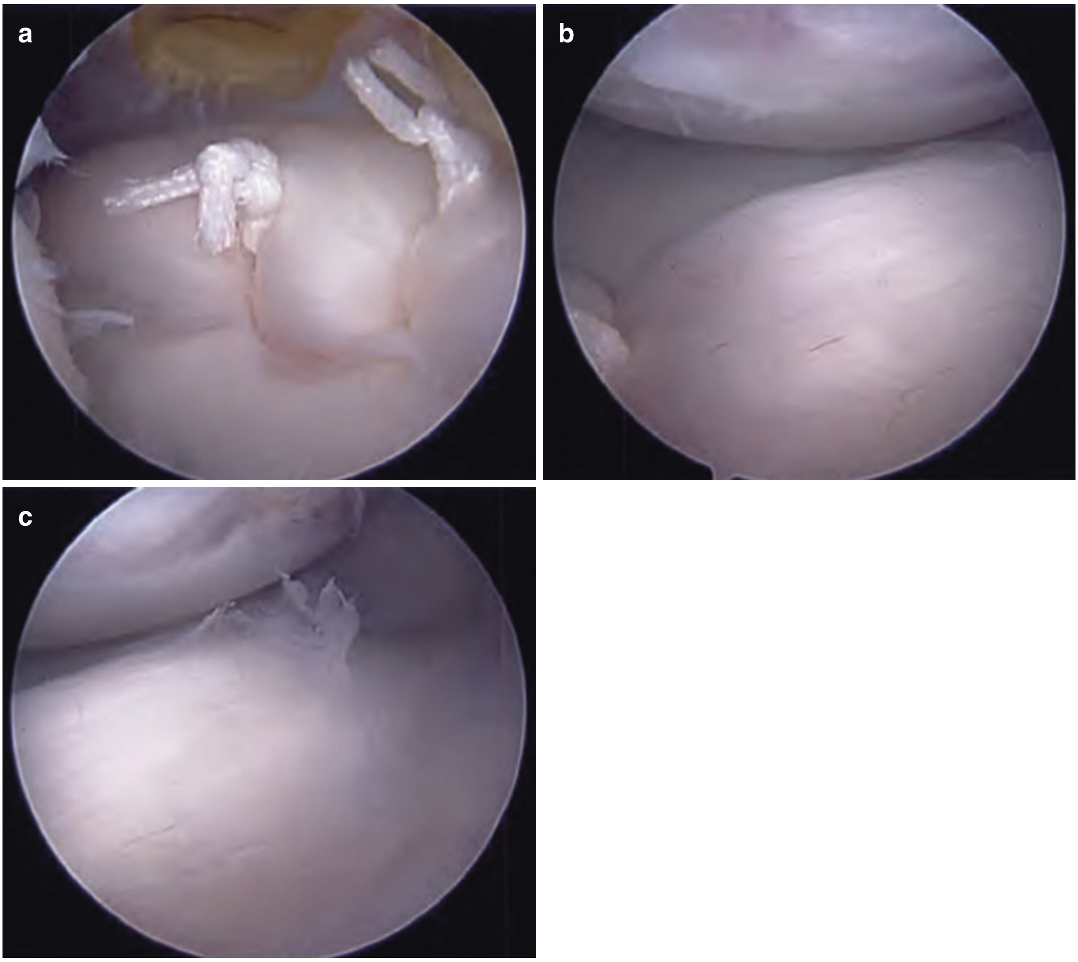

Fig. 26.6 Simple suture configuration securely reattaching the labrum (**a**), recreating the posterior bumper (**b**), and re-tensioning of the PIGHL (**c**)

voluntary scapular retraction. His modified dynamic labral shear test was negative. He could perform his normal work activities and returned to baseball activities with no pain on throwing, although he noted decreased power and distance on hard throws. He rated his global rating of change as +2 (moderately better after treatment).

Summary

This case illustrates the concerns surrounding proper evaluation of the labral injury, relating the labral injury to the clinical presentation and treating the labral injury to restore the clinical function. The labrum is now known to have roles in shoulder function of being a bumper to deepen the glenoid socket and provide edge stability, a dynamic attachment site for the biceps [17], and a washer to evenly spread the loads across the joint and center the ball in the socket [18] and to provide tension in the PIGHL [12].

The clinically significant labral injury can affect shoulder function by impairing some of the roles resulting in the disabled throwing shoulder [12, 19]. The patient can exhibit pain upon abduction and external rotation in cocking, indicating increased posterior-superior translation and internal impingement, weakness in overhead positions; indicating pain or loss of humeral head position and symptoms of internal derangement (clicking, popping, or sliding); indicating loss of the bumper effect, washer effect, edge stability, or decreased capsular tension or a “dead arm”; and indicating loss of proprioception, decreased capsular tension, and increased translation. Very rarely can the SLAP injury create alterations responsible for the clinical symptoms. The presence of a SLAP lesion has poor correlation with the presence or absence of clinical symptoms [20]. The clinical symptoms are more correlated with the propagation of the superior tear into the posterior and inferior labrum, creating enough anatomic injury to affect the labral roles in edge stability, bumper protection, and ligament attachment and tension that allows loss of concavity/compression [21]. This is equivalent to a type 8 SLAP lesion. Surgical treatments that fail to address all of these issues are associated with less good outcomes [11, 13, 22].

This patient’s clinical course is consistent with these principles. His initial history was consistent with a clinically significant labral injury, and the initial treatment, focusing on alteration of activity and rehabilitation, was correct because rehabilitation can relieve the symptoms and improve function in a portion of symptomatic patients [15, 23, 24]. However, the first surgery did not address all of the pathoanatomy, resulting in continuation of the dysfunction, and by restricting biceps motion increased the dysfunction by adding pain and decreasing glenohumeral motion. The loss of fixation in the suture probably saved the biceps from anatomic damage.

The diagnostic evaluation of a failed surgery needs to be extensive. The patients need to have as much information as possible in order to make an educated decision about further treatment. The history should be detailed: what were the initial complaints, were they compatible with a labral injury? There is evidence that labral surgery has been done without adequate documentation of the proper diagnosis [11]. What was the operative technique, if available, and what were the postoperative rehabilitation details? The clinical examination should be comprehensive, evaluating the kinetic chain, scapular position and motion, glenohumeral range of motion, rotator cuff and biceps, and specific clinical tests for labral integrity. The modified dynamic labral shear test has the highest demonstrated clinical utility of any labral test [6] and has been shown to be helpful in identifying labral injury, especially in combined injuries or failed surgery. Imaging can be helpful in confirming the diagnosis and as a preoperative planning tool. The conventional axial view allows good tangential visualization of the posterior inferior labrum, while the oblique axial view allows better tangential visualization of the posterior labrum.

The revision surgical treatment was successful in achieving the surgical objectives. The correctness of this approach was confirmed by the benign postoperative course, the relief of symptoms, and the restoration of effective function and the global rating of change score of +2 (moderately better after treatment). It also confirmed that revision surgery for failed SLAP surgery does not require biceps tenodesis if there is no evidence by history, clinical examination, imaging, or arthroscopy that the biceps is clinically damaged.

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27

A 28-Year-Old High Level Volleyball Player with Sore Shoulder

Giovanni Di Giacomo and Nicola de Gasperis

Introduction

The shoulder is the most mobile joint in the human body. Its anatomical design provides stability allowing a wide range of motion in all directions. This leads to a fragile equilibrium between stability and mobility, especially in the throwing player, who is trying to generate as much energy as possible for the serving motion. The thrower's shoulder must be loose enough to throw but stable enough to prevent humeral head subluxation and to maintain control during the entire throwing motion (acceleration and deceleration phases). Hence the thrower's shoulder is in delicate balance between mobility and stability. The sport of volleyball has significant potential for shoulder injury due to the repetitive nature of the overhead spiking, serving, and blocking activities. Several types of overhead motions are used by volleyball players when training and competing. The spike or attack is the most explosive and is used to terminate a point, with speeds reported at up to 28 m/sec in elite players [1]. An elite-level volleyball player can execute up to 40,000 spikes in a single season. Additionally, two types of serves are used, the traditional float server and the more explosive jump serve. These overhead motions can be broken down for biomechanical study into five phases, similar to throwing or the tennis serve: windup, cocking, acceleration, deceleration, and follow-through [2]. Reeser et al. performed a biomechanical study of the cross-body spike and straight-ahead spike in elite volleyball players. They found players to use approximately 160° to 163° of combined external rotation during the cocking phase of the spike and ball contact to occur at 130° to 133° of abduction. This position of abduction at ball contact is moderately higher than values reported for baseball pitching and the tennis serve. At ball contact, the horizontal adduction angle averaged 29° to 33°, placing the shoulder in the scapular plane at values very similar to those reported in other overhead sports. Similar values for shoulder external rotation (158–164°), shoulder abduction at ball contact (129–133°), and horizontal abduction (23–30°) were reported by Reeser et al. for the jump serve and traditional float serve in elite volleyball players. Shoulder internal rotation velocities in one study ranged between 2444°/sec and 2594°/sec during arm acceleration before ball contact. Similar internal rotation velocities were reported for the jump serve, with significantly slower (1859°/sec) velocities present during the float serve. Muscular activity patterns of the rotator cuff are similar to observations in other reports in overhead athletes, with greatest subscapularis (65% maximum voluntary isometric contraction [MVIC]), pectoralis major (59% MVIC), and latissimus (59% MVIC) activity occurring during the explosive internal

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rotation in the acceleration phase of the volleyball spike. Interestingly, the teres minor shows a peak in activity of 51% MVIC during acceleration to provide posterior stabilization to the accelerating humerus. Activation levels of 34–37% MVIC are reported in the supraspinatus, infraspinatus, and teres minor during arm deceleration in the volleyball spike, highlighting the important need for eccentric stabilization to resist distraction forces at the glenohumeral joint and maintain glenohumeral joint integrity [1–3]. The repetition of the abduction-external rotation movement of the arm during the overhead action carries an increased risk of overloading various structures around the shoulder. The cause of shoulder pain in the overhead athlete is very difficult to identify and diagnose. Pathologic contact between the posterior margin of the glenoid and the articular surface of posterosuperior rotator cuff tendons is known as posterior internal impingement (PII) [4–6]. Young overhead athletes, continuously performing high-velocity throwing actions over the years, usually go to specific osseous and soft tissue adaptations. Adaptive anatomic changes in thrower athletes that can lead to internal impingement include glenohumeral internal rotation deficit (GIRD), increased humeral and glenoid retroversion, acquired glenohumeral anterior/posterior instability, scapular weakness, and concomitant rotator cuff weakness. The chronic repeated compression or impingement leads to articular tears of the rotator cuff tendons as well as lesion of the superior labrum (SLAP lesions).

Case-Based Approach: Clinical Evaluation and Pathophysiology

A 28-year-old professional volleyball player came to our clinic 1 year after the beginning of a right shoulder (dominant side) pain and discomfort during sport activity that has worsened in recent months. The main pain occurred during service and smash motion with a loss of velocity and accuracy, and he complained about not being able to perform sport activity at a high level. He also felt some “click” in abduction and external rotation movements. He didn’t have before any trauma on his right shoulder. Physical exam revealed a normal range of motion (ROM) except for internal rotation with a positive GIRD (approximately 20° of internal rotation less than the contralateral limb) and pain during elevation or external rotation with the arm at 90° of abduction. He also had few positive tests including the active compression test, modified dynamic labral shear test, uppercut test, resisted supination external rotation test, and pain on the long head of the biceps (LHB). Preliminary x-rays didn’t show any bone defect. At this point the diagnosis was not so clear, and we decided to do an MRI to evaluate patient’s rotator cuff, LHB, and glenoid labrum. When the physical exam is clear and sufficient for a correct diagnosis, we usually first try to treat the patient with a rehabilitation program. In this case the uncertainty of the diagnosis and the psychological aspect, not to be underestimated in the professional athlete, made us decide for an early MRI to make a definitive diagnosis. The MRI showed PII signs on the humeral head and on the posterosuperior aspect of the glenoid and a possible SLAP lesion (Figs. 27.1 and 27.2). Several explanations have been developed to

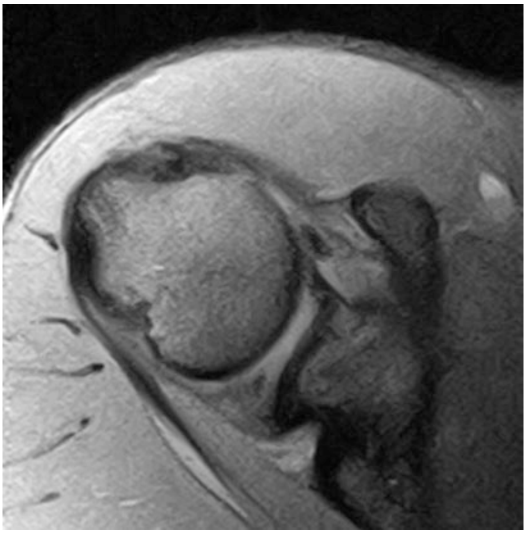

Fig. 27.1 MRI axial view of a professional volleyball player showing posterior impingement signs on the humeral head and on the posterosuperior aspect of the glenoid

Fig. 27.2 MRI frontal view of a professional volleyball player showing SLAP lesion signs

clarify the pathogenesis of shoulder injuries in overhead athletes. One explanation is that the repetitive nature of the serve causes microtrauma of the anterior capsule. Elongation of the ligaments may be responsible for subtle instability. The anterior displacement of the humeral head shifts the center of rotation to a more anterior position. This probably brings, in abduction and external rotation (ABER) position, the greater tuberosity and rotator cuff tendons close to the posterior glenoid, causing PII [7]. Although PII occurs in healthy shoulders, it can become pathological in the overhead athletes. PII is characterized by pain in the posterior aspect of the glenohumeral joint of overhead-throwing athletes during the late cocking phase of the throw, where the arm is in a position of full external rotation and abduction of at least 90°. The pain is due to a compression of the supraspinatus and infraspinatus tendons by the posteriorly rotated greater tuberosity of the humeral head against the posterosuperior portion of the glenoid. This occurs when the humeral shaft moves posteriorly beyond the plane of the scapular body during the cocking phase of throwing [8]. Another common finding in overhead athletes is a change in the rotational arc of the shoulder. Usually, there is an increase in external rotation and a decrease in internal rotation caused by posteroinferior capsular contracture [9, 10]. It has been suggested that there is an association of glenohumeral internal rotation deficit (GIRD) with the development of shoulder injuries [11]. If the limitation of internal rotation exceeds the gain in external rotation, resulting in a decrease in rotational arc (>10% of the contralateral side), the shoulder is susceptible to injury [12]. The stiffness and shortening of the posterior structures have consequences for stabilization of the shoulder during abduction and external rotation. According to O'Brien et al., the IGHL is the most important stabilizing capsular component in the shoulder (anterior band in abduction-external rotation; posterior band in internal rotation) [13]. In the position of abduction and external rotation of the shoulder, the posterior IGHL is positioned under the humeral head. In the case of a functionally shortened posterior IGHL, a posterosuperior-directed force exists, shifting the center of rotation of the shoulder to a more posterosuperior location. This posterosuperior shift can lead to anatomical lesions of the labral complex (SLAP lesion).

Case-Based Approach: Conservative Treatment

Definitive diagnosis of SLAP lesion requires arthroscopic evaluation. Nevertheless conservative management of PII and SLAP lesions is often the first line of treatment and has been shown to be successful. Not all SLAP tears require surgical intervention, and approximately 70–80% of patients who undergo surgical fixation can expect to return to their previous sports [14–18]. Every overhead athlete requires a training program that strengthens all elements of the kinetic chain of the throwing motion. Patients with mild symptoms and early phases of the disorder need active rest, including a complete break from throwing along with physical therapy. Anti-inflammatory measures to "cool down" the irritated shoulder can be beneficial in accelerating the rehabilitation process. This includes nonsteroidal anti-inflammatory drugs (NSAIDs) and occasionally a corticosteroid injection. Athletes with longer-lasting problems need a rehabilitation program emphasizing dynamic stability, rotator cuff strengthening, capsular stretching, and a scapular stabilization program [19–21]. Therefore the patients have been conservatively treated for 3 months with a specific rehabilitation program divided into four phases:

Rehabilitation program *Phase 1*: the primary aims of the rehabilitation program are aimed at allowing the injured tissue to heal, at modification of activity, at decreasing pain and inflammation, and on the re-establishment of a baseline dynamic stability, correction of the muscle balance, and restoration of proprioception. In addition, the athlete's activities (such as throwing and exercises) must be modified to a pain-free level. Active-assisted motion exercises may be used to normalize shoulder motion, particularly shoulder internal rotation and horizontal adduction. The thrower should also perform specific stretches and flexibility exercises for the benefit of the posterior capsule and rotator cuff muscles.

Rehabilitation program *Phase 2*: the primary goals are to intensify the strengthening program, continue to improve flexibility, and facilitate neuromuscular control. During this phase, the rehabilitation program is progressed to more aggressive isotonic strengthening activities with emphasis on restoration of the muscle balance. Selective muscle activation is also used to restore muscle balance and symmetry. Contractures of the posterior structures, the pectoralis minor muscle, and the short head of the biceps muscle also contribute to a glenohumeral internal rotation deficit and increase the anterior tilting of the scapula. Borstad et al. found the "sleeper stretch" to be effective for a stretch on the posterior aspect of the shoulder [22]. Several authors have emphasized the importance of scapular muscle strength and neuromuscular control as a contribution to normal shoulder function [23]. Isotonic exercise techniques are used to strengthen the scapular muscles. Overhead-throwing athletes often exhibit external rotator muscle weakness. Also during this second rehabilitation phase, the overhead-throwing athlete is instructed to perform core-strengthening exercises for the abdominal and lower back musculature. In addition, the athlete should perform lower extremity strengthening and participate in a running program including jogging and sprints. Upper extremity stretching exercises are continued as needed to maintain soft tissue flexibility.

Rehabilitation program *Phase 3*: the goals are to initiate aggressive strengthening drills, enhance power and endurance, perform functional drills, and gradually initiate throwing activities. Dynamic stabilization drills are also performed to enhance proprioception and neuromuscular control. An interval throwing program may be initiated in this phase of rehabilitation.

Rehabilitation program *Phase 4*: This phase usually involves progression of the interval throwing program as well as neuromuscular maintenance. The goal is to return to the full throwing velocity over the course of 3 months. Nevertheless, after the conservative treatment, the patient presented only slight improvement in clinical symptoms. We therefore decided to proceed with the surgical treatment.

Case-Based Approach: Surgical Treatment

Several open and arthroscopic tenodesis techniques have been described, but none of them seems to be superior to another. The marginal benefits of SLAP repair surgery have led some surgeons to consider biceps tenodesis as an alternative procedure [17, 24–28]. To date the literature does not provide evidence to support one technique over the other, and there are advantages to each procedure. The patient then underwent arthroscopic surgery that showed a type II SLAP lesion with extension on the posterior labrum that was repaired arthroscopically (Figs. 27.3 and 27.4). In the presence of a type II SLAP lesion, the labrum should be reattached to the glenoid and the biceps anchor stabilized utilizing suture anchors. Postoperatively the patient did well with no complications. Arthroscopic surgery has been followed by 3 weeks of cast and 4–5 months of specific rehabilitation program initially based on passive motion exercises and

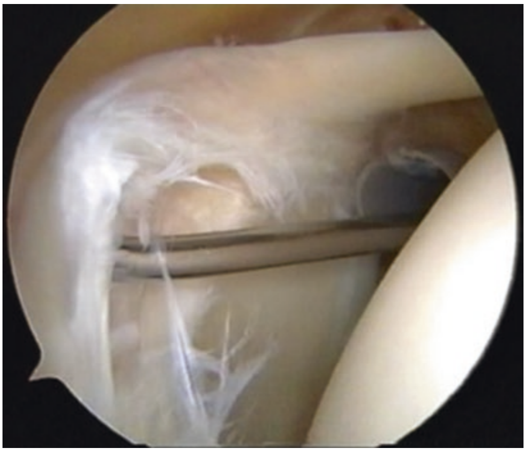

Fig. 27.3 Arthroscopic view of a type II SLAP lesion

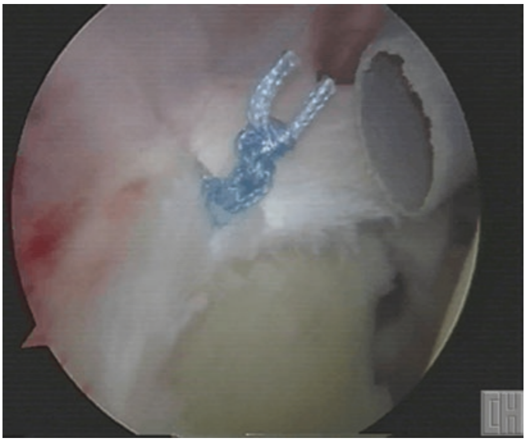

Fig. 27.4 Arthroscopic view of a type II SLAP lesion repair

restoring of ROM, followed later by the four phases of the conservative rehabilitation program without throwing activities until the third month after surgery. After 6 months from the surgical treatment, the patient was able to return to play at the same level before surgery.

Conclusion

The vast majority of shoulder injuries in overhead athletes should initially be approached with a conservative treatment. Only significant structural injuries deserve early surgical intervention. Every overhead athlete requires a training program that strengthens all elements of the kinetic chain of the throwing motion. To prevent the effects of overtraining or throwing, it is essential to instruct the athlete what to do through specific exercises throughout the year. Further investigation is needed to help determine which patients are likely to succeed with nonoperative treatment and those who will predictably do well with surgical repair. Most clinical studies on this topic are from single institutions and lack the power necessary to definitively draw conclusions about the superiority of specific management options.

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28

A 32-Year-Old Recreational Overhead Athlete with Tears of the Biceps, Labrum, and Rotator Cuff (Partial)

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Case Report

A 32-year-old right hand-dominant female with no significant medical problems presented to our office with 5 months of recurrent right shoulder pain. She is an avid softball and volleyball player. Her initial injury occurred while sliding head first into a base when she felt a pop in the shoulder. She denied any dislocation event at the time and after short rest was able to complete her season. When she started her volleyball season, she began experiencing anterior shoulder pain and a sense of instabilitys. She denied having any night pain and had no prior surgeries or injections. An initial trial of physical therapy failed to fully relieve her symptoms.

On examination the patient could forward elevate to 180°, externally rotate 60°, and internally rotate to T8. This was symmetric to the contralateral side. She had no bicep tendon and acromioclavicular joint tenderness. She had 5/5 rotator cuff strength on all rotator cuff testing. She did have a positive internal rotation compression test, dynamic labral shear test, but a negative Speed's test. She did have mild apprehension and relocation signs. Plain radiographs demonstrated no osseous pathology. MRI was significant for likely superior labral tear with possible anterior extension and signal involving the posterior superior rotator cuff.

Background

A thrower's shoulder is a complex system requiring strength and flexibility that overtime makes physiologic and biomechanical adaptations. The demand on the shoulder can lead to pathological and non-pathological findings on examination and imaging. The transition from adaptive to pathological conditions within a thrower's shoulder was well described by Burkhart et al. [1, 2]. Three of the major conditions facing a throwing shoulder include superior labrum anterior to posterior (SLAP) tears, partial articular-sided rotator cuff tears (PRCT), and biceps pathology. The surgical management of these problems only achieves satisfactory outcomes in the overhead and throwing athlete population with an average return to sport of 68% [3]. In this chapter we will discuss the diagnosis and management of SLAP, rotator cuff, and biceps pathology.

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SLAP Tears

Tears involving the superior labrum-bicep complex (SLBC) are generally broken into four major types: (1) labral fraying with intact bicep anchor, (2) labral fraying with detachment of bicep anchor, (3) bucket handle tear of labrum with intact bicep anchor, and (4) bucket handle tear of the labrum that extends into the bicep anchor [4, 5]. Additional subtypes of SLAP tears were defined by Maffet et al. [6], but the initial four types still account for a majority of diagnosis. SLAP tears are common injuries among overhead throwers and manual laborers. In throwers, classically the repetitive throwing motion with abduction and external rotation leading to a "peel-back mechanism" [7] is the primary cause, but others have noted the traction injuries on follow-through as possible sources [8, 9]. Diagnosis of SLAP tears is difficult as the history and physical exam can be mixed. In general the predominant complaints are pain and loss of velocity or control [1, 8]. Physical examination has also proven inconsistent in diagnosing SLAP tears [10–13], leading many clinicians to develop their own algorithm of what exam tests they rely on to diagnose bicep-labral injuries [14]. Our senior author (BJC) regularly relies on a proper history, assessing the timing and onset of symptoms, understanding the qualitative nature of symptoms and the aggravating factors, and differentiating extra-articular complaints from those that seem to originate from an intra-articular location. Physical examination findings including the dynamic labral shear test and internal rotation compression test are commonly performed when testing for SLAP lesions with diagnostic intra-articular injections to further evaluate the source of pain. Adding to the diagnostic complexity is that SLAP tears rarely occur in isolation. They are often diagnosed with concomitant pathology including rotator cuff tears, labral tears, and subacromial pathology in nearly 90% of cases [15, 16]. In these cases the use of diagnostic injections to the glenohumeral joint and biceps tendon sheath can be useful in differentiating the primary source of the patient's pain and pathology [17]. Another aide in diagnosis is advanced imaging, specifically MRI and MRI arthrogram, the latter of which remains the gold standard for diagnosis of SLAP tears [18, 19]. Abduction and external rotation (ABER) sequences may be useful in throwers as it closely recreates the "peel-back" mechanism and has shown similar sensitivities and specificities as MRI arthrograms [19]. It is the senior author's experience that an MRI arthrogram is rarely needed as a standard MRI in combination with proper history and physical can typically make the diagnosis.

Treatment of SLAP tears as with all throwing injuries should start with nonoperative management. Throwing results in a myriad of adaptive changes that are picked up on imaging but may not be pathological and a short course of "core to floor" physical therapy with an emphasis on normalizing scapular mechanics and improving internal rotation deficits may help rebalance the shoulder and allow the athlete to return to their sport. Nonoperative management has proven successful in SLAP tears including high-level athletes [20–23]. Edwards et al. [20] saw 71% of their athletes and 67% of throwing athletes return to their sport. Possible risk factors for failure of nonoperative treatment include history of trauma, positive compression test, and overhead activities [23]. Unfortunately, more elite throwing athletes have not shared the same success. In a review of a single major league baseball organization, only 40% of pitchers returned to play compared to 85% of field players. Only 22% returned to a previous level of play following nonoperative management [21]. Despite these lower success rates in elite throwers, we agree with conclusions of Fedoriw et al. [21] that nonoperative management should always be the first step in treating SLAP tears given inconsistent outcomes following surgical interventions.

There is still much debate that surrounds the surgical treatment in bicep-labral complex injuries. Type I and type III tears are treated with debridement; however, treatment of type II tears remains unclear. The issue lies in the structural role of the bicep and superior labrum in the throwing shoulder. Some have argued the bicep is a vestigial organ [24] or solely a pain generator [25], while others have argued that the bicep and labrum function as glenohumeral stabilizers [26–30]. Mihata et al. [31] demonstrated that the disruption of the bicep-labral complex leads to increased laxity especially in throwers. There remains some discussion about how well these cadaver studies translate to the playing field because we are not aware of what is clinically significant translation and could not account for non-capsular contributors to glenohumeral stability [24, 32]. In terms of clinical results, systematic reviews have demonstrated the younger athlete doing well following SLAP repair [33–35]. In general the return to sport following SLAP repair is 70–80% [34, 36, 37], but despite excellent functional scores, throwers have not been able to return to sport at the same rate as non-overhead athletes [33–41]. One significant factor is the presence of partial thickness rotator cuff tear often bode worse for return to sport/throwing in patients with repaired SLAP tears despite excellent functional scores [42, 43]. If in isolation, a SLAP tear should be repaired in a young thrower of any level who has failed non-operative treatment.

Recently there has been more discussion of the use of bicep tenodesis to address SLAP and bicep pathology in athletes. In their study of 20 patients who had their SLAP tears treated with primary tenodesis, Pogorzelski et al. [44] found 80% of their overhead athletes returned to sport. Only two of these patients, however, were throwers. The concern of treating throwers with tenodesis is the perceived role of the bicep-labral complex in stability of the throwing shoulder [30]. An electromyographic and motion analysis study countered this belief by demonstrating that pitchers regain normal neuromuscular control and mechanics regardless of SLAP repair or tenodesis [45]. Tenodesis has also been shown a viable option in revision cases of failed SLAP repairs even with an 81% return to sport [46]. Our senior author (BJC) believes that while tenodesis is a viable option for SLAP tears in primary and revision cases, it should still be used with caution in young overhead athletes [47].

Partial Rotator Cuff Tears (PRCTs)

The development of partial rotator cuff tears as a result of internal impingement has been well described [1]. The impingement of the posterior superior rotator cuff at the extreme of abduction and external rotation is a common finding in throwers, but is not always pathologic. Some hypothesize that partial tears result from the supraphysiologic demands placed on the shoulder, especially in elite throwers [48]. Ninety-one percent of partial tears are articular-sided tears [49] of the posterior supraspinatus and superior infraspinatus [19, 50, 51] and will be the focus of this discussion. While first described by Codman in 1934, the classification of partial tears was established by Ellman et al. [52] and then Snyder et al. [53], who also helped describe the partial articular-sided tendon avulsions (PASTA) that are common in overhead throwers. As with SLAP tears, PRCTs present with pain, loss of velocity, or control and often have insidious onset [54]. Physical examination of the injured throwing shoulder should always include evaluation of the pathological cascade outlined by Burkhart et al. [1] with a special focus on loss of internal rotation and total motion compared to the non-throwing arm [55]. Aside from ruling out other sources of pain (acromioclavicular, cervical, or bicep/SLAP), specific isolated testing of each rotator cuff muscle should be performed. Impingement signs (Neer/Hawkins) can be positive in partial tears but are not reliable diagnosis. It is not uncommon for bursitis, however, to be a concomitant and secondary diagnosis. Numerous physical exams have been used to detect partial tears and internal impingement, but none have proven reliable [51, 54]. Currently our senior author (BJC) performs evaluation of shoulder range of motion with a focus on assessing total arc of motion and relative differences in internal rotation, standard rotator cuff strength testing, and additional pathology-specific tests to rule out other pathologies. Advanced imaging remains crucial in the diagnosis of partial tears. Specifically, MRI arthrogram and MRI in ABER positioning have proven to have better sensitivity than classic MRIs [19]. A signal within the rotator cuff is a common finding in up to 40% of asymptomatic throwers

[56] and often presents for 5 days after throwing in a game [54].

Nonoperative therapy is the mainstay of treatment among throwers due to the low return to play rates following surgical interventions and the fact that surgical intervention is not otherwise required to alter the natural history of a problem. In other words, only patients who have impaired performance and have failed nonoperative treatment should be considered for surgical intervention in this population. The focus of treatment is rest (cessation of throwing), anti-inflammatory medication, and physical therapy with a focus on range of motion (especially stretches to address capsular contractures most commonly present in the posteroinferior capsule) and rotator cuff strengthening [1]. After initial rehabilitation, the patient transitions to core strengthening and a throwing program to regain proper mechanics. Pain is the key to progression through the rehabilitation program, which can average 3 months but will vary case by case [54]. There currently is not any significant literature on specifically treating partial rotator cuff tears nonoperatively in throwers, although these rarely occur in isolation and are commonly seen in asymptomatic individuals.

Failure of nonoperative measures (persistent pain and failure to advance through a throwing protocol) should occur prior to considering surgical intervention in a throwing shoulder. The mainstay of surgical treatment of partial rotator cuff tears is debridement [9, 51, 54, 57]. Debridement of partial tears has proven successful in the general athletic populations [53]. The key to debridement is removal of degenerative tissue and then marking the area with a spinal needle and PDS suture. The bursal side of the tendon is then inspected to evaluate the degree of involvement. In the general population, partial tears exceeding 50% are recommended for repair, which has a return to sport of 84.7% and return to previous level of 65.9% [58]. But given the poorer outcomes in the throwing population, current expert opinion suggests repair at 75% involvement [54]. Payne et al. [49] looked at the outcomes of 40 athletes (75% overhead), who underwent debridement of partial rotator cuff tears. The study at first glance found successful outcomes, but there were significant differences in satisfaction and return to sports between the acute traumatic patients (86% and 64%, respectively) and the chronic/insidious patients (66% and 45%, respectively) [49]. The throwing athlete is different from other overhead athletes because the disease process is likely initiated by an adaptive phenomenon leading to a chronic and degenerative process due to repetitive microtrauma [59]. The worse outcomes in younger and throwing populations are supported by a recent systematic review by Lazarides et al. [50]. In regard to elite throwers, Reynolds et al. [57] saw 76% return to play but only 55% return to previous level in 82 professional pitchers. Repair of partial tears has also had limited success with a wide range in return to sport. Ide et al. [60] saw only 33% return following transtendon repair. Conway et al. [61] had 89% of their patients return to play in a cohort with concomitant SLAP or anterior instability. The decision between debridement and repair is more than just about tendon involvement. Concomitant pathology, age, and career arc should all be considered and discussed with the patient. In general, more elite throwers would benefit with debridement, while recreational athletes would be more likely to benefit from repair in order to preserve long-term function. It is important to note that when deltoid pain is a primary complaint that the rotator cuff may be an important contributor to the disabled throwing shoulder.

Bicep Pathology

The anatomy of the long head of the biceps tendon with its course from the supraglenoid tubercle down the intertubercular groove makes it prone to injury [62, 63]. This anatomy often results in intra-articular pathology at the biceps-labral complex, but tendonitis of tendon can extend extra-articular in the majority of cases [64]. The patient often presents with anterior shoulder pain that can radiate down the arm and can even experience mechanical symptoms (popping or clicking) in cases of biceps subluxation/

dislocation [65]. Pain extending beyond the elbow is more likely cervical in nature. While patients may have tenderness over the bicep sheath, physical examination of the biceps tendon is difficult as it rarely occurs in isolation [66]. Thus reliance on multiple physical examination tests helps improves the diagnostic sensitivity for biceps tendonitis [10, 67]. Taylor et al. [67] demonstrated that the absence of tenderness and a positive internal rotation compression and dynamic labral shear test can reliably exclude extra-articular biceps pathology. The combination of palpation, Speed, Yergason, and having the patient perform an uppercut is often used in our clinic for diagnosis. Advanced imaging with MRI still has difficulty diagnosing pathology of the biceps tendon with an overall sensitivity of 77.3% and 40–50% for junctional and intertubercular sites [68]. Without a single reliable test, ultrasound-guided biceps injections have been gaining popularity as both diagnostic and therapeutic interventions in our clinics.

Management of biceps tendonitis begins with nonoperative measures that work to decrease inflammation (rest and anti-inflammatories) with physical therapy to treat concomitant pathology that may be leading to biceps irritation including modalities and eccentric strengthening. Currently, there are no major studies that evaluate the results of nonoperative measures for biceps tendonitis [65]. In cases where nonoperative measures fail, the dichotomy of surgical intervention revolves around biceps tenotomy or tenodesis. Biceps tenotomy has proven a quick and reliable treatment with easy rehabilitation in older populations [25, 66]. But there remains concern over the cosmesis of the “Popeye” deformity and cramping that can occur following tenotomy [66]. Biceps tenodesis decreases the occurrence but initially requires a more protected rehabilitation. As a result, two separate systematic reviews currently recommend tenodesis in younger, higher-demand, and worker’s compensation populations, but both agreed that a discussion with the patient should occur to understand expectations [69, 70]. The incidence of tenodesis is increasing [71], and many successful techniques have been described [72].

Tenodesis has had good success with young athletic populations [73]. As mentioned earlier, there has been concern of performing tenodesis in overhead athletes, especially throwers [30]. A recent motion analysis and EMG study, however, demonstrated no significant difference in pitching mechanics between those who received bicep tenodesis or SLAP repair when compared to controls [45]. In fact, Chalmers et al. [45] found that SLAP repairs demonstrated significantly thoracic rotational movement when compared to tenodesis and control groups. Tenodesis has proven itself a reliable intervention for both biceps pathology and SLAP pathology [24]. Pogorzelski et al. [44] showed 80% return to sport in their overhead athletes, but only two were throwers. In cases of biceps tendonitis with concomitant SLAP pathology, primary bicep tenodesis demonstrated significant improvement in ASES, SANE, SST, and VAS scores [74]. In elite baseball players, however, the return to prior level of sport after tenodesis is 35% (80% for position players and 17% for pitchers) [75]. The outcomes may be skewed as the cohort was predominantly pitchers and all patients had additional procedures performed. There was a trend that players who did not receive a reconstructive procedure had better return to prior level of sport (44% versus 25%). While these are not encouraging results, they are similar to the general return to previous level of sport among baseball players following any shoulder or elbow procedure [76]. This reenforces the concept that a thrower’s shoulder is a complex system with significant adaptations that does not consistently respond well to surgical interventions. With this in mind, tenotomy has no significant role in a recreational athlete with isolated biceps tendonitis who has failed conservative measures; we generally recommend bicep tenodesis. With more elite athletes, including most overhead athletes, tenodesis is still our primary recommendation for biceps tendonitis and SLAP tears with concomitant biceps pathology, but one should use significant caution with performing a tenodesis in a thrower, as there remains limited clinical evidence on outcomes.

Concomitant Pathology

As mentioned previously, SLAP tears, partial articular-sided rotator cuff tears, and biceps pathology rarely occur in isolation [15, 16, 66]. Albeit in an older and general population, combined SLAP repair and rotator cuff repairs have done well compared to rotator cuff repair alone [77], as have those treated with rotator cuff repair and tenotomy [78, 79]. A more recent randomized trial of patients undergoing rotator cuff repair with SLAP tears found no difference in outcomes between the three treatment arms of biceps debridement, tenotomy, and tenodesis [80]. The cohorts for these studies tended to be older than 40 years of age, with limited athletic populations. There are small studies showing reasonable outcomes in recreational and some elite overhead athletes. Gupta et al. [74] had 80% satisfaction rates in patients who had biceps tenodesis for SLAP tear and biceps tendonitis on examination. Eight of their patients were athletes ranging from collegiate to recreational, and only one patient reported failure to return to their sport. Additionally, a study out of Turkey looking at 34 elite athletes (32 labeled overhead, but 8 were soccer players) who underwent SLAP repair with associated injuries (labral tears, partial and full thickness rotator cuff tears) found an 88.2% return to prior level to play at 6 months [81].

Baseball players have not shared these outcomes. Due to the adaptations in a throwing shoulder, most surgeons have taken a “less is more” approach [82] when treating pathology. Neri et al. [43] reported on 23 overhead athletes who underwent Type II SLAP repairs. Despite excellent functional scores, only 13 patients (57%) were playing pain-free, 6 were playing with pain, and 4 were unable to return to sport. The one significant risk factor for being unable to return to sport was the presence of a partial thickness rotator cuff tear, which was debrided at time of surgery. Another study reporting the outcomes of combined SLAP and rotator cuff repair in elite throwers found only 35% of the cohort returned to pre-injury level [83]. A return to sport of 89%, reported by Conway et al. [61], is the outlier to the trend that any surgery involving rotator cuff repair in a thrower can expect around a 33% chance of returning to previous level of play [60, 83].

Case Intervention and Outcome

The patient who presented to the senior author’s clinic was a 34-year-old female softball player who sustained a left shoulder injury while sliding into a base. Since that time, she had been experiencing significant anterior shoulder pain. Physical exam showed a positive Speed’s test, positive Yergason’s test, as well as pain over the bicipital groove. MRI had confirmed that the biceps had subluxed out of the bicipital groove (Fig. 28.1a, b). The patient underwent arthroscopic evaluation (Fig. 28.2a–c).

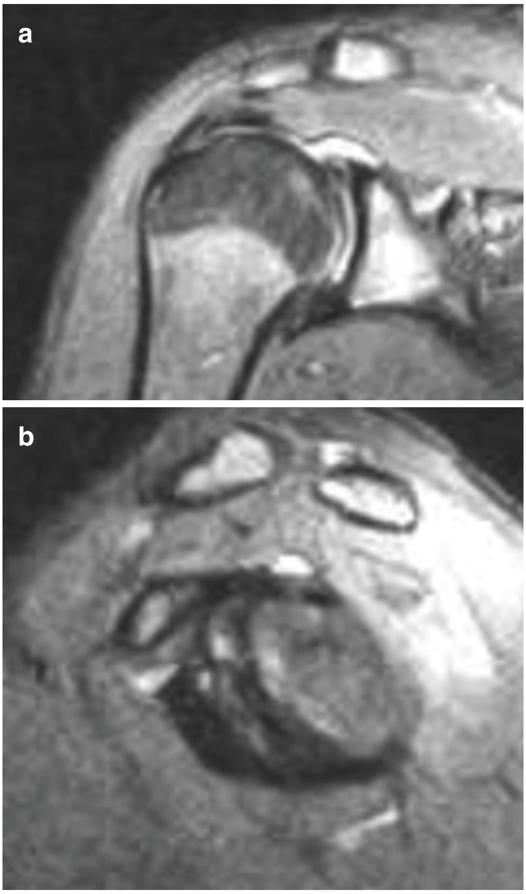

Fig. 28.1 MRI imaging (**a**) coronal, (**b**) sagittal

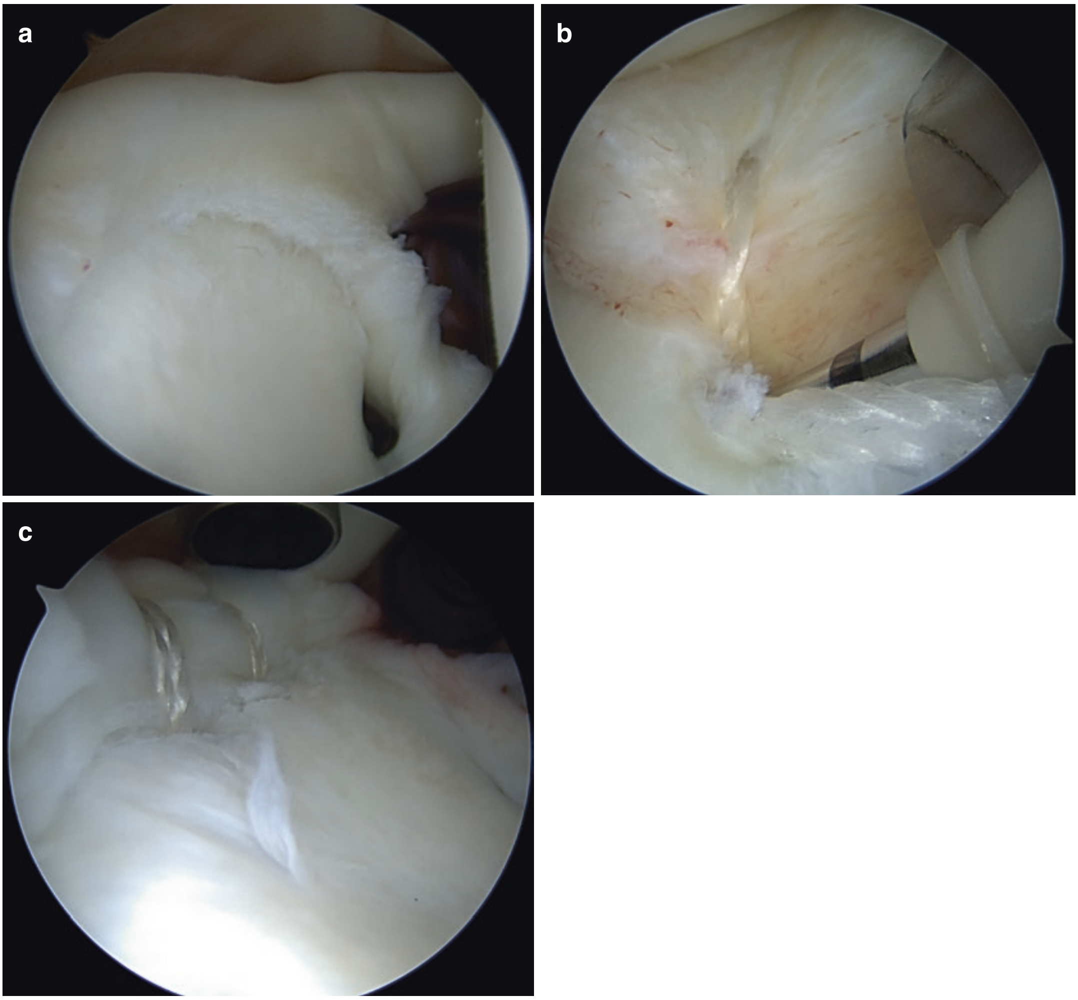

Fig. 28.2 Intra-op imaging (**a**) SLAP tear, (**b**) push-lock fixation of labral tear, (**c**) completed SLAP repair

Inspection of the glenohumeral joint showed a type 2 SLAP tear with anterior extension as well as degeneration and tendinosis of the biceps. In addition to the SLAP tear, the patient had a concomitant 75% involvement in articular-sided tear of the posterior supraspinatus. A spectrum suture shuttle was used to pass labral tape through the labrum and then fixed with a PushLock® anchor. These steps were repeated until the SLAP tear and anterior extension were secure. At this point, a smaller shaver was used to debride the remaining labral fraying. The rotator cuff was then debrided including the exposed footprint followed by placement of a corkscrew anchor into the footprint of the supraspinatus. In situ repair was performed with single row to reestablish the medial footprint. A 2.5 cm incision was made in the anterior aspect of the humerus just inferior to the pectoralis and then dissected down to the biceps. A double-loaded FiberTak® anchor was placed in the anterior aspect of the humerus, and a free needle was used to place a #2 FiberWire® in cinch stitch configuration using a Mason-Allen stitch to secure the long head of the biceps to the anchor. An additional #2 FiberWire® was used to secure the tip of the biceps tendon to the pectoralis.

Postoperatively the patient was placed in sling with abduction pillow. Codman exercises with wrist, and elbow range of motion was allowed until first postoperative visit. Physical therapy was initiated with passive range of motion until week 4, followed by active range of motion with strengthening beginning week 8. The patient was cleared for gradual return to sport by the fourth month and reported full return to sport by 6 months postoperatively.

Conclusion

Our senior author (BJC) believes that symptomatic pathology should be addressed in an athlete who fails nonoperative management. In non-overhead athletic populations, rotator cuff tears should be treated as we would in the general population with respect to debridement versus repair after maximizing nonoperative treatment. Type II SLAP tears that fail nonoperative treatment should undergo SLAP repair in a majority of cases unless the patient is a non-throwing athlete with concomitant bicep tendonitis. In those patients, a primary biceps tenodesis can be considered. In the throwing population, we agree with Caldwell et al. [82] that "less is more" in that partial rotator cuffs should be debrided and type II SLAP tears should be repaired. In all cases the patient should be counseled on the outcomes and expectations of each procedure in regard to general function and return to sport. This is especially true among throwers who demonstrated significantly worse return to sport and previous level compared to their non-throwing peers. Finally, in the event that a bicep tenodesis is required, overhead athletes can still return to high-level competitive play, but the prognosis remains more guarded than in the non-overhead athlete.

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29

A 60-Year-Old Recreational Athlete with a Rotator Cuff Tear and Repair

W. Ben Kibler

History

The patient is a 60-year-old male with right (dominant) shoulder pain for the last 18 months. Symptoms are of mild pain on overhead or external rotation activities, slight weakness on heavy overhead lifting, decreased muscle endurance, and difficulty in hitting hard tennis serves. He could still be active in both tennis and golf. He had rare exacerbations of the symptoms, but they resolved with short periods of rest and over-the-counter medications. He had no formal treatment, but did "rotator cuff exercises" as part of a twice weekly work-out program.

Two months ago, he went on a week-long golf outing, playing 27 holes a day. He had a non-traumatic but acute increase in his symptoms after the third day, with increased weakness in overhead and forward flexion activities, decreased arm abduction strength and motion, and enough pain on rotation that he could not play for 2 days. He tried to play the last day but could only play nine holes. In addition, he had nighttime discomfort, not being able to lay on his right side.

He had not played golf or tennis since and did not do the rotator cuff exercises for 5 weeks. The limiting pain has decreased, and he was able to increase his arm forward flexion and abduction. However, he continues to have decreased strength and nighttime pain. He restarted his exercises 2 weeks ago but could not progress in weight loading or repetitions. Golf and tennis swing motion create pain along the lateral aspect of the shoulder. Because of continued limiting symptoms and no resolution as with previous episodes, he sought medical advice.

Physical Exam

Kinetic chain exam demonstrated no leg or hip weakness to one leg stability testing. He had asymmetrical tightness to right lateral trunk tilt and right trunk rotation, with mild pain and stiffness to lumbar extension. He demonstrated a type 2 scapular dyskinesis (entire medial border prominence) both at rest and upon arm motion in elevation and descent [1]. He demonstrated weakness of lower trapezius and serratus anterior in the low row maneuver. He had pain to palpation and tightness to stretching in the upper trapezius and pectoralis minor. He had positive impingement signs, with relief of symptoms with the scapular assistance test (SAT) [1].

Shoulder exam revealed well-developed musculature, with no supraspinatus or infraspinatus atrophy. He had pain to palpation along the lateral acromion. Glenohumeral range of motion was 45° internal rotation/30° external rotation at 0° of abduction and 30° internal rotation and 20° external

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rotation at 90° of abduction. Arm forward flexion was 110° actively and 130 passively. He had 4−/5 external rotation and forward flexion strength to manual muscle testing, with pain. He had a decrease in the pain but no change in strength upon the scapular retraction test (SRT) [1]. Internal rotation strength was 5/5. Biceps exam showed no anterior groove tenderness or instability, with 5/5 strength. Neurological exam was normal, and there was no glenohumeral joint instability upon the relocation maneuver and testing.

Imaging

Plain radiograph series demonstrated minimal glenohumeral joint changes, no narrowing of the acromiohumeral space, and mild AC joint changes. Due to the recent relatively acute change in symptoms, the chronicity of the mild symptoms, and the patient's anticipated desire to return to sports activity, and MRI was performed, in order to provide comprehensive information to establish the extent of the anatomic lesion and guide the content and timing of the treatment. The MRI demonstrated a 3–4 cm tear in the supraspinatus and anterior infraspinatus tendons, with minimal retraction, no involvement of the biceps, no fatty infiltration, and no muscle atrophy (Fig. 29.1).

Fig. 29.1 T2 Coronal image showing detachment of supraspinatus tendon from the greater tuberosity

Diagnosis

The clinical history and exam are consistent with a rotator cuff injury, with an acute exacerbation of symptoms due to the acute change in exercise exposure and load. Although speculative, the increased dysfunction probably represented an enlargement of the tear, probably into the infraspinatus, to the size seen on the MRI. In addition to the anatomic lesion, physiologic alterations include muscle stiffness in the upper trapezius and pectoralis minor, decreased glenohumeral joint rotation, and imbalance in the anterior/posterior force couple. Biomechanical alterations included trunk stiffness and resultant decreased motion and scapular dyskinesis. These distant alterations increased the loads on the rotator cuff and are all associated with rotator cuff dysfunction.

Initial Treatment

The clinical and radiological findings and the patient's anticipated functional activities were included in the discussion of the operative and non-operative treatment options. The patient desired to regain as much capability to play golf and tennis as possible but also was not ready to undergo surgery as the first treatment option. Therefore a non-operative program was instituted, focused on the alterations identified. The kinetic chain component addressed the trunk stiffness and weakness, starting with core stabilization. The scapular component addressed scapular retraction control, improving lower trapezius and serratus anterior activation and strength, as well as pectoralis minor and upper trapezius flexibility. The shoulder component addressed improving glenohumeral joint mobility in internal rotation and external rotation and rebalancing the anterior/posterior force couple activation and strength. This comprehensive approach has demonstrated good result in decreasing the need for surgery on a high percentage of patients with chronic tears [2], with improvements noted around 6–10 weeks. The patient was also maintained on a modified activity program, with no overhead lifting and no golf or tennis for 6 weeks. Because of the tear size, acute exacerbation of the symptoms, and the anticipated desired activities, there was a concern that the tear could further enlarge, so the need for close follow-up and reevaluation was emphasized.

Follow-Up

The patient returned at 6 weeks. Rehabilitation logs demonstrated good compliance with the protocols. The patient reported decreased pain and slight increase in motion, but minimal improvement in strength and two attempts to play golf and one attempt to hit tennis balls were unsuccessful. Exam showed symmetrical trunk rotation and less pain to extension, mild type 2 dyskinesis only upon arm descent, and mild soreness over the pectoralis minor. Glenohumeral external rotation and internal rotation were improved to 50° and 40°, respectively. External rotation and forward flexion strength were still rated at 4−/5 off a stabilized scapula. There was minimal functional improvement, both subjectively and objectively, even though some of the physiological and biomechanical alterations were improved. Upon further consultation, surgical treatment was recommended and accepted.

Surgery

The patient underwent arthroscopy which confirmed the clinical and radiographic diagnosis (Fig. 29.2). Arthroscopic rotator cuff repair was performed using two medial anchors and a double-row suture bridge construct (Fig. 29.3). Postoperatively, he was kept in a sling for 3 weeks. He progressed into a closed chain, short lever arm, and co-contraction rehabilitation protocol [3]. No loading was allowed for 6 weeks, and no overhead positioning was allowed for 8 weeks. Kinetic chain, trunk, and scapular muscle activation was started at 10 days, so that when the rotator cuff repair was strong enough for loading, the proximal base could facilitate optimal rotator cuff activation [4–6]. At 3 months, he demonstrated kinetic chain activation coupled with scapular retraction and arm elevation up to 120°. At 4 months, he demonstrated full trunk motion and 4+/5 muscle strength in external rotation and forward flexion and was allowed to start chipping and putting and limited tennis ground strokes. At 6 months, he demonstrated good overhead strength and was allowed normal golf activities and was started on tennis serve progressions.

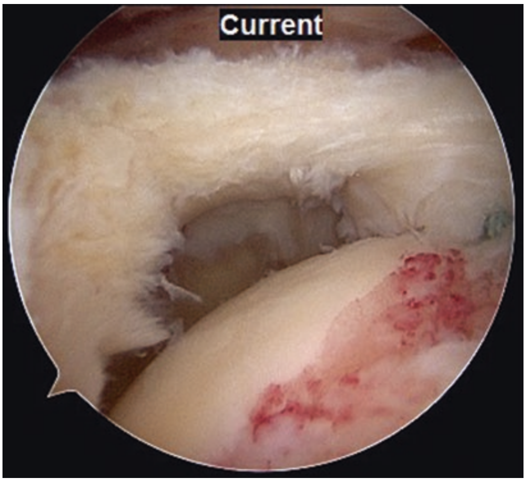

Fig. 29.2 Arthroscopic view from posterior portal showing tear of supraspinatus away from the footprint

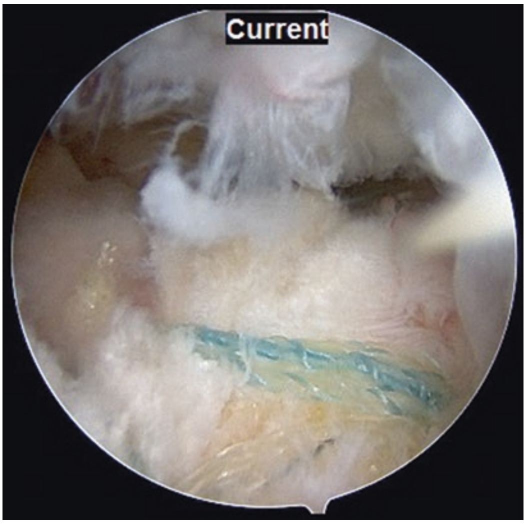

Fig. 29.3 Arthroscopic view of the completed rotator cuff repair demonstrating reattachment of the rotator cuff to the footprint

Summary

This case illustrates a common clinical presentation of rotator cuff disease. There can be a lengthy period of mildly limited activities with an acute change in function, probably due to a new injury that increases the size of the tear and disrupts the compensatory mechanisms that have accompanied the gradual progress of the injury. If an appropriate rehabilitation that addresses all the alterations identified on clinical exam does not restore the compensatory mechanisms, surgical repair is recommended early in the course of the disease. This patient was at increased risk of tear progression, and surgery can be expected to produce a repair that will avoid the progression to larger tears and muscle atrophy that mitigate against optimal outcomes.

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A 50-Year-Old Female Masters Swimmer with Shoulder Pain

Klaus Bak

History

The patient is a 50-year-old female Masters swimmer who was referred with increasing right shoulder pain that limits training and competition. She has had pain for over 6 months, which is gradually worsening. Currently, she is unable to swim and experiencing pain at night. She is facing a regional Masters competition in 2 months and a national championship event in 4 months. The patient had a history of starting her swimming career at the age of 8 years. She was a competitive swimmer until the last year in college after which she stopped her career due to education and family. During her early career, she never experienced shoulder pain. She resumed swimming at the age of 40, and until the injury occurred, she had been training and competing with no significant pain. The pain started after a training camp where she increased her training amount from three times 1.5 hours training sessions per week to two daily training sessions of 3 hours in total per day. There had been no history of a fall on the shoulder and no history of a sudden pain during dryland training. She mainly experiences pain on the lateral side of the shoulder but also on the anterior aspect of the shoulder from time to time. The pain has become increasingly worse during the last months preventing her from swim training. During swimming practice, she often experienced clicking from the shoulder joint. Her previous treatment included a cortisone injection in the subacromial space that had only limited effect. She reported that she had had eight sessions with a physiotherapy that included rotator cuff exercises and occasionally laser treatment. She has experienced no improvement from this treatment; on the contrary she reported that the rubber tube exercises often led to aggravation of pain.

Physical Examination

The clinical examination revealed that her active range of flexion and abduction movement reached normal ranges, but the movement of the arm was asynchronous which was interpreted as a combination of pain and lack of scapular control. External range (ER) of motion was normal with the elbows at the side but limited to 80° in 90° abduction which is considered abnormal in a swimmer that normally exhibits increased ER. She had no signs of glenohumeral internal rotational deficit. The Hawkins test, Jobe abduction test, O'Brien's test in pronation and dynamic shear test were positive. The patient was then evaluated for scapular dyskinesis by observing her performing repeated abduction and flexion [1–5]. Already after one repetition, she displayed

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increased anterior tilt and a prominent inferior scapula angle. The scapula retraction test (SRT) showed that her abduction strength and her pain improved, whereas the scapula assistant test (SAT) showed improvement of pain-free active abduction. She was tender on palpation of the pectoralis minor tendon just medial of the coracoid process. The latter findings both indicate that the scapula dysfunction has been present for a long time and that correction of scapular mechanics may be susceptible to physiotherapy intervention. Apart from examining shoulder function, distant factors that may alter the final force transmission through the shoulder girdle should be evaluated. Even in swimmers, kinetic chain dysfunctions may lead to overload of the shoulder girdle, such as reduced hip flexibility, back pain and core stability [6, 7]. In the present case, she showed normal hip mobility but reduced mobility of the lower back, and her cork screw test was positive for left leg squatting indicating core instability possibly due to an unresolved lower back problem. She reported of previous recurrent low back pain but without significant MRI findings. Limited mobility of the lower back may affect swimming speed as well as power transmission across the kinetic chain which in turn may increase the load demands of the shoulder.

Imaging Diagnostics

Evaluation with imaging diagnostics included plain X-rays with an AP view and a Y view of the glenohumeral joint and a Zanca view of the acromio-clavicular joint. In overhead athletes, X-rays are mainly used to exclude other diagnoses. In the present case, X-rays showed no bony abnormalities apart from osteoarthritic changes of the acromioclavicular joint where no tenderness could be found. The ultrasound (US) examination showed increased thickness of the supraspinatus tendon and fluid in the subacromial bursa. The long head of the biceps tendon (LHB) was seen with normal thickness and no signs of tearing. There was a slight increase in the fluid in the synovial sheath, but no signs of LHB instability during dynamic examination with rotation of the arm.

The interpretation of ultrasound and magnetic resonance imaging must be done with caution in swimmers with shoulder pain. Like other overhead athletes, swimmers may develop adaptive changes that are needed to perform swimming. These changes may often be a normal finding and, therefore, not the treatment. A good example is tendinopathy of the supraspinatus tendon that has been shown to be associated with shoulder pain in swimmers [8]. Increased volume of the supraspinatus tendon does, however, not predict the overall treatment plan and the prognosis. Ultrasound may show altered signal or even increased thickness of the long head of the biceps tendon and excessive fluid in the tendon sheath. The latter can be due to a peritendinitis of the LHB, which is often a result of an increased humeral head translation created by scapular dyskinesis. In overhead athletes it may also often be a sign of intraarticular pathology with the excess fluid coming from the joint. These findings lead to an MR arthrography (MRA). The MRA showed both tendinopathy of the supraspinatus tendon and posterior-superior labral pathology. There were no signs of instability pathology such as anterior or posterior labral avulsions, Hill-Sachs lesion or Bankart lesion. Overall, the clinical working diagnosis was a combination of supraspinatus tendinopathy and a posterior-superior labral avulsion together with peritendinitis of the LHB all aggravated or maintained by scapular dysfunction. A history of the previous back pain may have affected the kinetic chain.

Challenges of the Interpretation of the Clinical Evaluation

The major challenge when interpreting the clinical evaluation and imaging diagnostics in swimmers with shoulder pain is that no finding can stand alone. The typical condition that leads to shoulder pain in a Masters swimmer is a conglomerate of multiple factors of which many are susceptible to exercise intervention or manual therapy. Imaging diagnostics is used to exclude other causes of pain and to join together the tentative findings during the clinical examination and related pathology documented on MRA or ultrasound.

The four most common pain syndromes seen in Masters swimmers are (1) lateral shoulder pain and subacromial pain with or without a partial supraspinatus tear (LSP), (2) posterior-superior impingement with labral fraying or tear and possible associated partial supraspinatus tear (PSI), (3) anterior-superior pain due to upper labrum pathology affecting the long head of the biceps (ASI) and (4) anterior or bidirectional minor instability (AMI) [2, 9].

(1) Subacromial Pain with or Without a Partial Supraspinatus Tear (SPS)

In this case, pain may be a major obstacle for an exercise programme wherefore an injection of corticosteroid into the bursa may be a controversial but viable option in swimmers with constant pain. An injection should be followed by a careful explanation of possible temporary side effects (flare) and infection (very rare). In the timing of the treatment, it is important to monitor the development of the case. Is there any progression in treatment over time? In general, the literature recommends 3–6 months of rehabilitation, but no studies so far give clear answers. The therapist should be aware of lack of progression and refer back to the referring doctor if there is no sign of improvement. The swimmers that have mainly scapular, cuff-related and kinetic chain dysfunctions in general respond well to nonoperative treatment and may return to swim training within a few months. Cases with limited progression often display more pronounced rotator cuff pathology such as partial supraspinatus tears either on the undersurface or intratendinous or scapular dysfunctions not responding well to intervention. Suggestions for treatment intervention are listed in Table 30.1. If nonoperative treatment fails, an arthroscopy is indicated. A PASTA lesion can be debrided and in larger tears a repair is indicated. In cases with subacromial stenosis due to causes other than scapular dyskinesis, an acromioplasty may be indicated in individuals over 45 years. Surgical treatment of swimmer's shoulder has included partial distal clavicle bone resection, coracoacromial ligament resection, debridement or decompression. Return rates, however, are low and vary from 20% to 56% [10, 11].

(2) Posterior-Superior Labral Lesion Without Instability (PSI) and (3) Anterior-Superior Pain (ASI)

In the swimmers with predominately pain on the posterior aspect of the shoulder, the initial treatment is the same as above. This group also contains swimmers who have upper labrum and LHB-related pathology which often leads to anterior pain or clicking (ASI). As opposed to the group above, the structural pathology plays a larger role, and, therefore, the success rate after nonoperative treatment is lower. The initial treatment is the same as above, and the physiotherapist should again monitor expected progression. Corticosteroid injection in these cases should be intra-articularly to reduce inflammation of the synovia or in the bicipital sheath if excessive fluid is present as a result of labral pathology. If nonoperative treatment fails, an arthroscopy is indicated. Simple labral debridement and partial synovectomy may lead to success with regard to pain relief, but the return rate to swimming is low [10]. If the labrum is avulsed off the glenoid, the trend today is moving away from an anatomic repair with reinsertion of the labrum towards the increasingly popular tenodesis of the long head of the biceps. Level 4 studies through many years taught us that SLAP repair and other labral reinsertions were the gold standard, but lately it has become clear that the success rate in overhead athletes after this procedure is very low with a risk of permanently reduced external rotation, stiffness and pain [12, 13]. This reduces the return to overhead sport substantially. At the same evidence level, suprapectoral or subpectoral tenodesis has become increasingly popular due to a faster and higher return to sports and rare affection of external rotation. This is a biomechanical paradox since the LHB for many years

Table 30.1 Different clinical pain syndromes in "swimmer's shoulder"

	Pain location	Characteristic clinical signs	Primary treatment
Lateral shoulder pain syndrome (LSP)	Lateral	Hawkins test Jobe abduction test Scapula dyskinesis SAT and SRT	Physiotherapy addressing scapula and kinetic chain dysfunctions. Rotator cuff training. A subacromial cortisone injection can relieve pain and ease physiotherapy treatment
Post-superior impingement (PSI)	Posterior	Dynamic shear test O'Brien's test Scapula dyskinesis SAT and SRT	Physiotherapy addressing scapula and kinetic chain dysfunctions. Stretching – GIRD? An intraarticular cortisone injection can relieve pain and ease physiotherapy treatment
Anterior-superior impingement (ASI)	Anterior	Dynamic shear test Upper cut test O'Brien's test Speed's test Scapula dyskinesis SAT and SRT	Physiotherapy addressing scapula and kinetic chain dysfunctions. Rotator cuff training. Stretching – GIRD? Cortisone injection around the long head of biceps can relieve pain and ease physiotherapy treatment
Anterior minor instability (AMI)	Anterior	Apprehension test Relocation test Sulcus sign Scapula dyskinesis SAT and SRT	Physiotherapy addressing scapula and kinetic chain dysfunctions. Rotator cuff training. Stretching – GIRD? Cortisone injection rarely indicated

has been proven to have an anterior stabilising effect with the arm in the abducted position. The effect of this procedure seems to be related to a release effect of the unstable upper labral complex [14, 15].

(4) Anterior or Bidirectional Minor Instability (AMI)

This group often suffers from a sensation of instability together with pain, and the scapular dyskinesis may be secondary, wherefore intervention addressing this dysfunction is less often successful. The success of the treatment, therefore, can often be monitored by an increase in scapula control. If nonoperative treatment fails, the gold standard is a mini-open or arthroscopic anterior capsular shift.

In LSP, ASI and PSI, the scapular dyskinesis may most likely be primary due to frequent practice with high training amounts that may result in fatigue of the scapular stabilisers [3, 16], whereas in instability cases, it is more often a secondary phenomenon where scapula dyskinesis results from inability to centre the humeral head on the glenoid. It may be of importance to distinguish between these two types of scapular dyskinesis (SD) since primary SD more often responds well to physiotherapy, whereas in cases of AMI and secondary SD, the success rate of physiotherapy may be lower due to the redundant capsule.

Timing of Intervention for Treatment

Based on the clinical examination and the imaging diagnostics, the patient was offered a cortisone injection in the subacromial space. Cortisone injections are controversial and may have undesirable side effects, but nevertheless it provides an effective pain relief that is needed in patients with pain that restricts daily life, sleep and physiotherapy intervention. In addition, a rehabilitation programme was suggested aiming at correcting the scapular and kinetic chain dysfunctions including lower back problems. The aim of the treatment is to obtain pain-free full range of motion and a gradual return to swimming without recurrence. The physiotherapist was instructed to address weak muscles, such as the lower trapezius and the serratus anterior, and structures with too high tension such as the pectoralis minor tendon and the upper trapezius muscle. As part of the preventive programme, the coach was instructed to analyse and correct technical errors that may lead to early recurrence. A number of technical errors may lead to shoulder pain such as decreased body roll, unilateral breathing and excessive use of hand paddles. The goals of technique corrections are to (1) decrease the amount of internal rotation of the arm during the pull phase, (2) improve early initiation of external rotation of the arm during the recovery phase by improving body roll and (3) improve the posterior tilt angle of the scapula [17]. In the recovery phase and early pull-through, coaches should encourage the following: increased body roll and scapula retraction, aiming at normal strength and endurance of the cuff and scapular stabilisers, as well as improving the flexibility of the anterior capsule, pectoralis minor and the cuff [17].

The patient reported that exercise treatment preceded by a cortisone injection improved her daily life abilities, but she was not able to return to swim training. Due to her long course of symptoms and limited effect on function, she agreed to undergo arthroscopy. The arthroscopy confirmed the presence of an unstable upper labrum complex and signs of attrition of the upper humeral head that indicates biceps instability. In addition, the subacromial bursa was chronically inflamed with tissue strings colliding with the surface of the supraspinatus tendon. An arthroscopic subacromial bursectomy and a suprapectoral biceps tenodesis was performed followed by a three-phased physiotherapy programme emphasising range of movement exercises and scapula setting for 6 weeks and increased strengthening and stretching for the next 6 weeks.

Results of Intervention and Progression of Recovery

At 12 weeks she resumed light swimming and continued exercise treatment for another 2 months. She returned to full swim training and competition after this. A preventive programme with emphasis on scapular stabilisation and stretching was designed to avoid recurrence.

In the current case, with constant pain even outside training sessions, it is not likely that she would be able to compete after 2 months of intervention. If nonoperative treatment was a success, she may be able to return to training 8–10 weeks after intervention started and then may be able to compete at the championships at 4 months. Depending on the extent and grade of structural pathology and dysfunctions, the normal return to sport rate after nonoperative treatment in the present case would be 3–5 months. After debridement and subacromial decompression, the expected return time would be 4–6 months, whereas this time period is 1–2 months shorter after biceps tenodesis. In general, the time for return to sport is correlated to the duration of symptoms. After a stabilising procedure, full ROM is expected in 4–6 months after which swimming can be resumed. In all cases, the goal of treatment is also to reveal dysfunctions that are susceptible to continuous preventive exercises.

Conclusion

Shoulder pain in Masters swimmers can be due to technical or training errors. The swimmer presenting with shoulder pain should undergo a thorough interview and clinical examination. Pain location may point to one of the four common pain syndromes. Clinical examination should include assessment of dysfunctions of the scapula-thoracic joint and the kinetic chain since this may play a major role in aetiology and, therefore, in the intervention and subsequent preventive exercise programme. Interpretation of imaging diagnostics should be done with care. Most cases resolve with nonoperative intervention focusing on scapular and kinetic chain dysfunctions. At least four different clinical entities exist that can lead to shoulder pain in swimmers. When nonoperative treatment fails, arthroscopic treatment directed towards the structural pathology should be considered. In most cases a peel back or a SLAP lesion is present, and a biceps tenodesis seems to have a better prognosis for full return to sports than anatomic repair.

Conflict of Interests Klaus Bak is a consultant for Arthrex. There are no conflicts of interest related to this chapter.

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A 65-Year-Old Recreational Athlete with Refractory Severe Glenohumeral Arthritis

31

David M. Dines and Michael C. Fu

Case History

Our patient is a 65-year-old former major league professional baseball player who presents with progressive, nearly constant pain with activities in his left shoulder, which is his dominant arm. He has had pain for a number of years, starting in his playing days and worsening ever since. It has become more severe over the last 4–5 years. He is a very active person who plays golf and tennis, swims, and works out regularly. Until 3 years ago, he participated in Ironman competitions, though with difficulty in swimming. He now presents with substantial night pain as well.

He has used a number of different nonsteroidal anti-inflammatory drugs (NSAIDs) for many years and has had at least five intra-articular corticosteroid injections. He has also undergone numerous episodes of physical therapy emphasizing pain relief modalities, scapular strengthening, and protected range of motion without significant response. He has also had a series of viscoelastic supplementation injections, and 2 years ago, he underwent arthroscopic glenohumeral joint debridement, chondroplasty, and microfracture with only minimal improvement. His goal is to get pain relief and the ability to participate in recreational sports activities including possibly senior Ironman competitions, golf, and racket sports.

Physical Examination

On physical exam he is a well-developed gentleman in good health with no obvious deformity in his shoulders. Active range of motion (ROM) of his affected left shoulder shows asymmetric limitations in glenohumeral abduction (100°), internal rotation (L1), external rotation (25°), and forward elevation (95°), compared to normal range of motion in his unaffected right shoulder. In addition, there is a significant scapulothoracic component to his shoulder motion. His rotator cuff strength is intact, and long head of biceps tests is negative. He has no bicipital groove tenderness. Crossarm abduction is not painful. His neurovascular examination is within normal limits. Cervical spine and ipsilateral elbow examinations are normal.

Imaging

Plain film radiographs (Fig. 31.1) show severe glenohumeral joint space narrowing with inferior humeral head/neck osteophytes, posterior glenoid wear, and a Walch B2 glenoid.

Two-dimensional (2D) computed tomography (CT) scan with three-dimensional (3D) reconstruction revealed a B2 glenoid with 14 degrees of

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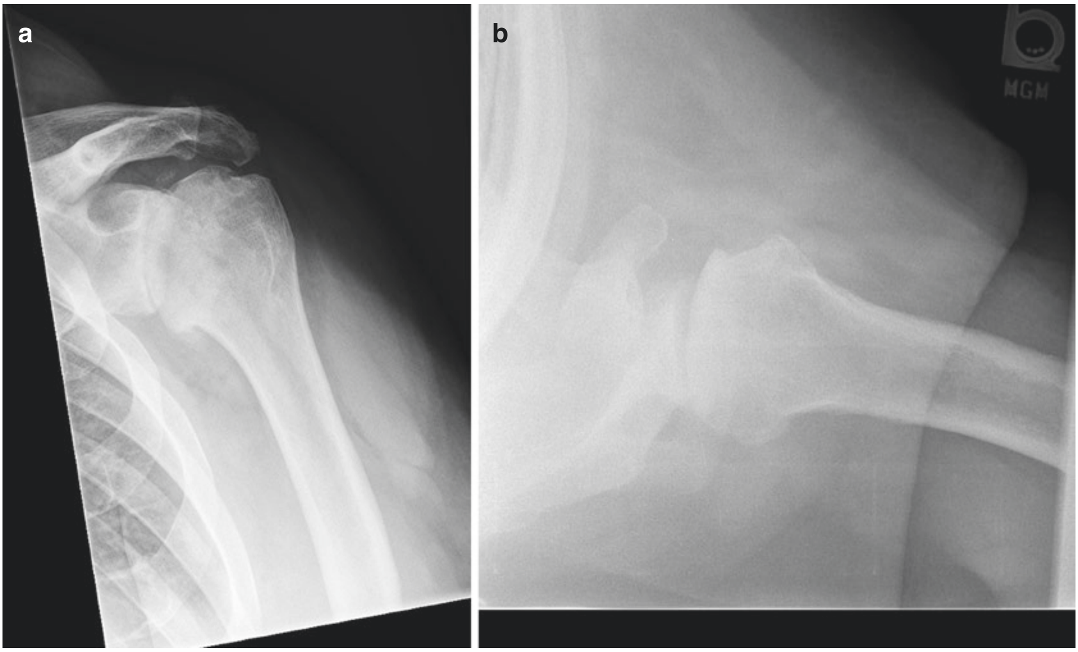

Fig. 31.1 Preoperative left shoulder anterior-posterior (**a**) and axillary (**b**) plain radiographs demonstrating joint space narrowing, inferior humeral osteophytes, and posterior glenoid wear

posterior glenoid retroversion but minimal humeral head subluxation (Fig. 31.2).

Indications and Preoperative Planning

This patient presented to our clinic for definitive care of his progressive glenohumeral osteoarthritis, with debilitating symptoms that have made it difficult to continue the active lifestyle he wishes to live. Night pain has also increased significantly in spite of the continued use of NSAIDs.

In addition to the above pertinent history, a comprehensive medical history was also obtained, including allergies to medicines or metals. Furthermore, an infection work-up was also completed, including aspiration under image guidance and serologic work-up consisting of C-reactive protein (CRP), white blood cell count, and erythrocyte sedimentation rate (ESR), which were all negative.

For this particular patient, we decided that the best procedure to allow him to maintain high load activity levels with maximum durable pain relief would be an anatomic shoulder arthroplasty utilizing a late-generation convertible platform humeral component implant with a polyethylene hybrid glenoid component consisting of cemented pegs with a titanium ingrowth post-design to ensure bone ingrowth fixation and maximum longevity. In addition, 3D preoperative planning software (Fig. 31.3) was used to create a custom 3D-printed patient-specific guide to ensure the best possible glenoid component positioning and fixation in this younger high-demand patient (Fig. 31.4). Finally, as is standard for our anatomic total shoulder arthroplasty, a subscapularis tenotomy is used and subsequently repaired with a double-row hybrid repair through both the bone and tendon.

Postoperative Course

Postoperatively, the patient was placed in a sling for 3 weeks. Pendulums and active abduction ROM was allowed immediately; however, active external rotation was limited to less than 10–20°

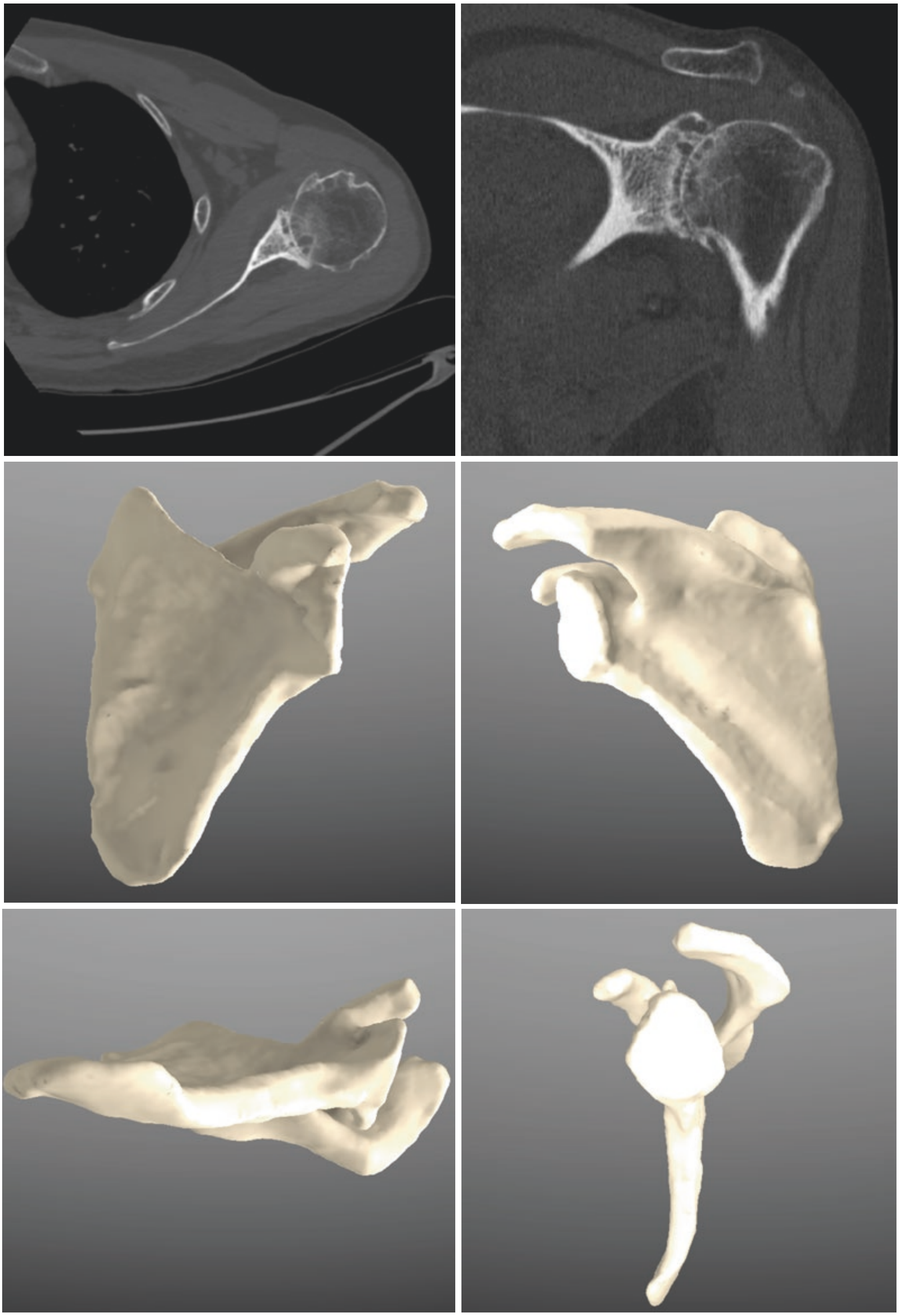

Fig. 31.2 Preoperative 2D CT and 3D reconstructions demonstrating a glenoid retroversion of 14 degrees, with minimal posterior head subluxation

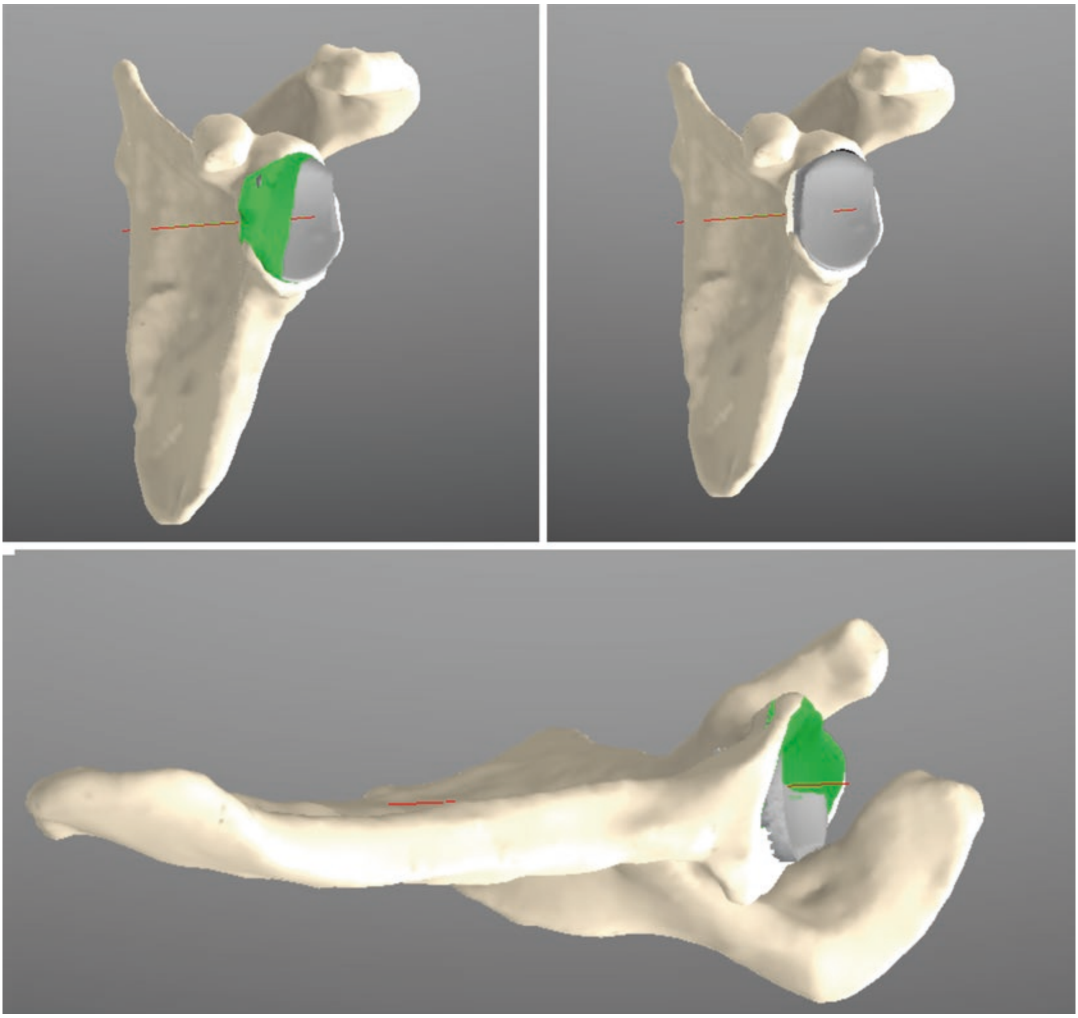

Fig. 31.3 Patient-specific preoperative planning software for optimal glenoid component positioning

for 4 weeks in order to promote maximal healing of the subscapularis tenotomy repair.

Formal physical therapy was instituted immediately in the hospital. It was centered on regaining motion through a protected passive ROM program while avoiding early external rotation as described above for the first 6 weeks. Active-assisted ROM was started at 3 weeks and strengthening of the deltoid, periscapular muscles, and rotator cuff by 4–6 weeks. This patient regained full active ROM very early. His pain was completely relieved, and he was able to return to all desired recreational sports and activities. Postoperative radiographs are shown in Fig. 31.5.

Discussion

In this case of a high-demand active patient with glenohumeral arthritis, we chose to do an anatomic total shoulder arthroplasty as opposed to a hemiarthroplasty. The hybrid glenoid implant used in this case has a biologic ingrowth component for fixation that yields better longevity even in higher demand patients and is convertible to other implant types if revision becomes necessary later.

The treatment of end-stage glenohumeral osteoarthritis in very active middle-aged patients who want to and will continue their active life-styles is complex, with a number treatment options and decisions. Studies published using data from our institution's shoulder registry demonstrate that nearly 67% of active patients undergoing total shoulder arthroplasty reported the ability to participate in sports and recreational activities at or above their current level as an important reason for undergoing surgery [1]. Implant durability and fixation in the face of younger age and higher activity level are important issues that must be considered. A number of surgical treatment options in active high-demand patients with refractory glenohumeral arthritis have been reported, including total shoulder arthroplasty, hemiarthroplasty with stemless or stemmed humeral components, and hemiarthroplasty with surface replacement with or without a "ream and run" procedure, and even biologic glenoid resurfacing has all been proposed in the treatment of this scenario.

Historically, younger patients were indicated for some type of hemiarthroplasty over total shoulder arthroplasty for fear of early glenoid component loosening seen in first-generation

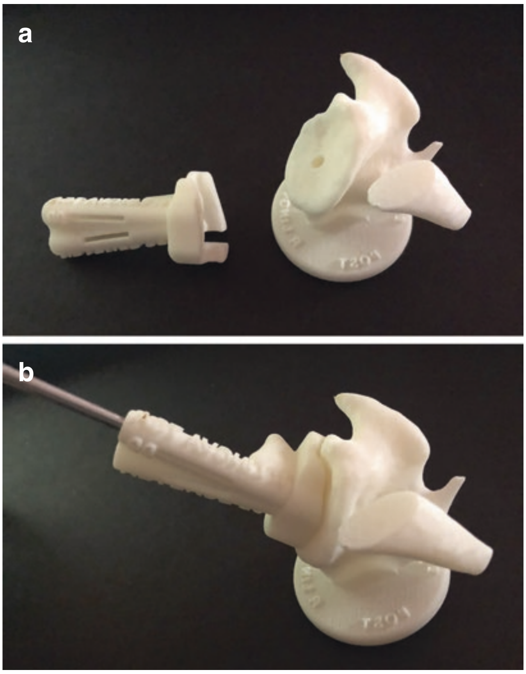

Fig. 31.4 Patient-specific 3D-printed guide for glenoid pin positioning. The custom aiming guide and a model of the glenoid shown separately (**a**) and engaged together to enable accurate guide pin placement (**b**)

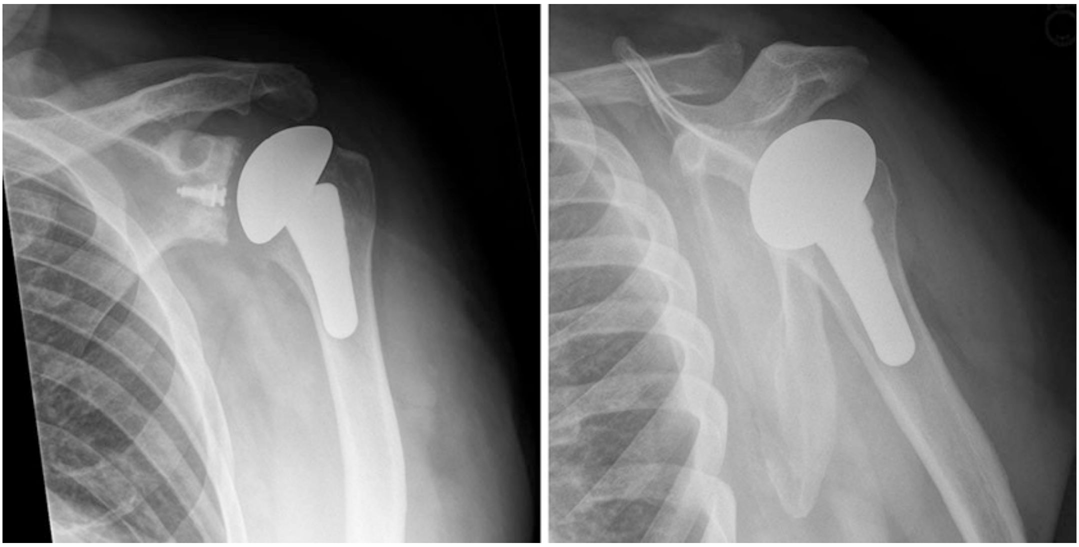

Fig. 31.5 Postoperative radiographs of the left shoulder

implants. In this context, Matsen et al. described the so-called "ream and run" procedure in which a hemiarthroplasty is performed in conjunction with reaming of the native glenoid surface to make it more concentric to the prosthetic humeral head [2]. This was based upon the early work of Levine et al. demonstrating that hemiarthroplasty in the setting of a concentric glenoid resulted in reasonable pain relief, durability, and function, while those with a nonconcentric glenoid had higher failure rates [3]. While reasonably good outcomes can be achieved in a subset of patients with the ream and run procedure following a long recovery period [4, 5], more recent studies on this procedure in younger and more active patients have demonstrated a revision surgery rate of 25% at a mean of 2.7 years after the index surgery [6].

Regardless of the type of humeral component used, the outcomes of hemiarthroplasty are inferior and short-lived relative to total shoulder arthroplasty, with only the perceived advantage of an easier revision to total shoulder arthroplasty later. In several landmark articles by Sperling et al. examining early generation implants in patients 50 years old or younger, the authors found only fair results after an index Neer hemiarthroplasty and relatively poor results when these patients were later revised to total shoulder arthroplasty [7, 8].

Using our institution's longitudinal shoulder arthroplasty registry, Garcia et al. compared the rates of postoperative return to sport between matched hemiarthroplasty and total shoulder arthroplasty cohorts [9]. All arthroplasty procedures were performed for primary osteoarthritis with a minimum follow-up of 2 years. We found a significantly higher rate of return to sport following total shoulder arthroplasty (36 of 37 patients, 97%) compared to the hemiarthroplasty cohort (19 of 29 patients, 65%). With sport-specific analysis, total shoulder arthroplasty remained superior to hemiarthroplasty with all sports examined.

Over the last few years, increasing sophistication in the understanding and classification of glenoid bone deformity in glenohumeral osteoarthritis has led to significant improvements in implant technology, imaging techniques, and patient-specific software planning tools. Operatively, this has evolved into the use of patient-specific guides and instruments in an attempt to improve the outcomes and longevity of total shoulder arthroplasty. Significant concurrent evolutions in glenoid component technology and biomaterials have also provided optimism for improved longevity of these implants.

In younger high-demand patients undergoing total shoulder arthroplasty, we believe that implant positioning in the setting of glenoid bone deformity is critical for successful and lasting outcomes. Therefore, in this particular case example, a patient-specific guide was created from his preoperative CT scan with 3D reconstruction. Furthermore, the latest generation of implant designs that allow for better bone ingrowth fixation and stronger polyethylene compositions will continue to improve glenoid component durability as well.

Activities after shoulder replacement have always been a concern for shoulder surgeons. With improvements in implant design and materials science over the years, however, activity restrictions especially with anatomic shoulder arthroplasty designs have diminished greatly. It is now standard of care to allow all recreational level sports, moderate weight training exercises, and other higher load activities. Contact sports, however, are not allowed in most cases.

Conclusion and Follow-Up

It is for these reasons that we chose to use patient-specific preoperative planning with a custom guide in this patient to ensure accurate anatomic glenoid component position. We utilized an anatomic-type total shoulder arthroplasty with a hybrid glenoid that consists of cemented pegs and a biologic bone ingrowth peg with the goal of achieving longer durability in this high-demand patient.

At 5-year follow-up, the patient is doing well and participating in all activities. His implant remains in a stable position with no evidence of loosening. Active patients with refractory glenohumeral arthritis who wish to continue sports participation should elect to undergo total shoulder arthroplasty to optimize their ability to return to play. While this operation will most likely provide excellent and durable results in terms of return to sports, nevertheless patients should still be counseled regarding appropriate postoperative activities to maximize implant longevity.

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