7 The Shoulder: Skeletal Injuries and Ligamentous Instability

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Shoulder injuries in the pediatric athletic population continue to increase with expanded participation and higher competitive levels of youth sports. Injury patterns are unique to the growing musculoskeletal system and specific to the demands of the sport involved. They could concern a direct contact from a collision or from a repetitive overhead motion. Both acute (sudden, traumatic) and chronic (long-term) injuries are common. Injuries requiring surgical intervention are even rarer. However, it is important for the practicing orthopedic surgeon to differentiate nonoperative injuries from the urgent and potentially operative injuries. Missing such an injury in the pediatric population could be potentially life threatening or lead to long-term disability. Open fractures or neurovascular-threatening fractures should be attended to immediately. Severely displaced proximal physeal humerus fractures in the older child often have a better long-term outcome after anatomic reduction. Finally, although glenohumeral dislocations, once reduced, are not life threatening or limb threatening, they do have a very high incidence of recurrence in adolescent patients. Posterior sternoclavicular dislocations should be differentiated from medial clavicular physeal injuries and promptly reduced. There is controversy regarding the appropriate treatment of these adolescent athletes—including debates on injury prevention, nonsurgical treatment versus surgical treatment, overuse injuries, and return to play after shoulder fractures, dislocations, and instability.

7.1 Anatomy and Development of the Shoulder

Understanding the anatomy in skeletally immature adolescents provides greater insight into typical pediatric and adolescent shoulder injuries. The major differences between the skeletally immature versus mature shoulder relate to the epiphyseal plates of the shoulder and collagen composition of the supporting ligaments and tendons. The proximal humeral epiphysis is responsible for 80 % of the humeral growth in length. The proximal humeral epiphyseal ossification, consisting in 3 different ossification centers, appears between the fourth and sixth months of life. The epiphyseal ossification core becomes radiologically evident in the first year of life. Between the second and third years of life, the second ossification core forming the greater tubercle and the third ossification core maturing to the lesser tubercle can be spotted radiologically. The tubercle core fuses with the core of the humeral head between the ages of 14

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and 16. Around the age of 20, the entire humeral epiphysis shows fusion with the diaphysis [1, 2].

The presence of the physeal plates of the shoulder provides matrices of lesser strength than those provided by the adjacent capsules and ligaments or even in some cases by the periosteum. The physis has an age-related variability in strength. Apparently the physis and its perichondral ring weaken just prior to maturity. This fact is borne out clinically in the classic study by Peterson [3], who found that the physeal injuries occurred between 11 and 12 years in girls and between 13 and 14 years in boys.

The shoulder, like the hip, is a ball-and-socket joint, but with a great lack of restriction. Different capsuloligamentous and muscular stabilizers ensure stability of glenohumeral joint. Static stabilizers include capsule and labrum and the superior, middle, and inferior glenohumeral ligaments. Dynamic stabilizers include the rotator cuff, long head of the biceps, deltoid, and scapulothoracic muscles [2].

The combination of weaker epiphyseal plates, weaker muscle forces, and excessive laxity of the supporting structures in the setting of significant forces to the shoulder region during sport may predispose the young athlete to shoulder injury. Additionally, it is known that the amount of Type III collagen (the major protein of ligaments and tendons) produced in adolescents is significantly greater than in adults, potentially leading to excessive laxity in the shoulder capsule and ligaments.

7.2 Specific Sporting Events and Injuries

7.2.1 Macrotrauma

Football: Football and wrestling produced the greatest number of injuries overall, whereas swimming and tennis had the lowest injury rates. They rank only second after the knee in overall injuries sustained in football.

Most injuries to the shoulder sustained in football result in macrotrauma (i.e., fracture of the clavicle or glenohumeral dislocation) and perhaps the outlawing of spearing, which brought a return of shoulder–body contact to tackling.

Wrestling: Twenty-nine percent of injuries occurring during high school wrestling season involve the upper extremity. Snook [4] found that almost 78 % involved the acromioclavicular (AC) joint. Such injuries are the result of a direct blow when the shoulder hits the mat. Since the object of wrestling is often to put leverage about the shoulder, one might expect. The incidence of glenohumeral dislocation, however, is quite low (less than 10 % of all shoulder injuries). This fact can probably be explained by the fact that the leverage forces applied to the shoulder are gradual and are strongly resisted by the muscular forces of the opponent.

Bicycling: Although bicycling is usually a recreational activity, it is becoming increasingly popular as an organized sport. Most bicycle injuries in the pediatric age group occur in children between 5 and 14 years old. In bicycle injuries, 85 % involve the upper extremity. One unique injury is the so-called “bicycle shoulder” (Fig. 7.1). This occurs when the cyclist is thrown over the front of the cycle when it is suddenly stopped. Failure to stay with the bicycle causes the cyclist to be thrown forward, landing directly on the shoulder. This forward propulsion over the wells produces a direct trauma to the Acromio-Clavicular (AC) area (fracture of distal clavicle or AC joint dislocation). A right teaching program explaining to the cyclist to maintain a tight grip on the handlebar and rolling with the cycle allows the body to absorb some forces of the fall, preventing shoulder injuries [5].

Skiing: During skiing, almost 30 % of the upper extremity injuries consist of shoulder dislocation or sprain. It was surmised that conditions that increased the speed of the skier, i.e., his ability and snow pack, increased the chances of sustaining an injury to the upper extremity [6].

Horseback riding: Two-thirds of the fractures sustained by young horseback riders occur in the upper extremities, after head and neck injuries. In Sweden, the major cause of fractures of the

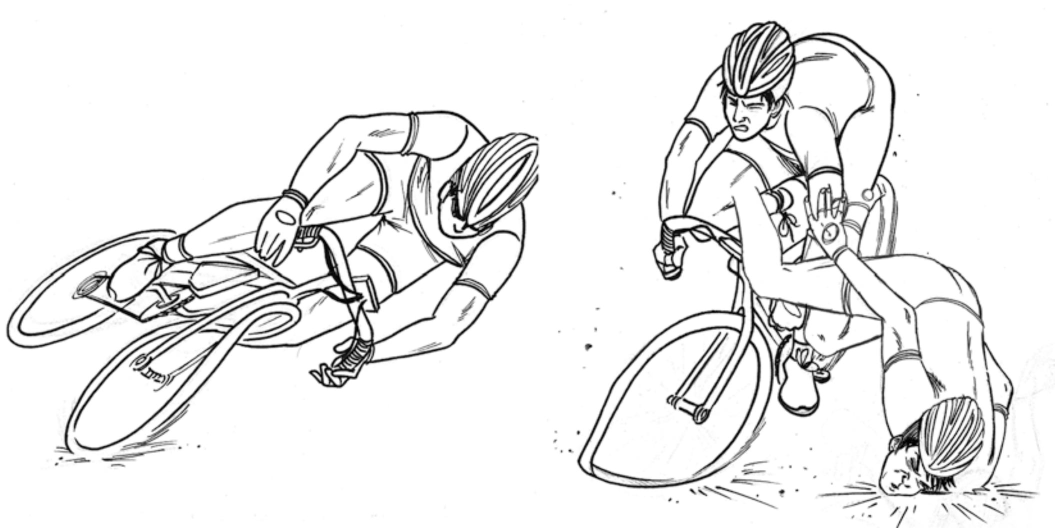

Fig. 7.1 Mechanism of trauma during cycling. Bicyclist lands directly on his shoulder after throwing forward over the handle bar. Falling in a proper and trained way leads a large distribution of force on the trunk preventing AC disruption or further shoulder major tears

proximal humerus in young girls is falling off the horse [7].

7.2.2 Microtrauma

Shoulder microtrauma and overuse syndrome can be divided into three categories: The first is *explosive* force such as that occurring in pitching a baseball; the second is *dynamic force*, sustaining a repetitive force for a longer period but without maximum forces such as in swimming; and the third is *static* in which isometric contractions are maintained across the shoulder for various periods of time.

Swimming: The most common orthopedic problem in competitive swimmers involves the shoulder and is almost exclusively seen in high-performance swimmers. In swimming, the athlete must pull the body over the arm. Athletes under the age of 10 rarely are affected by these injuries, but a dramatic increase is reported after that age. A unique aspect of swimming is the factor of upper extremity endurance. Competitive athletes may swim 10,000–14,000 m (6–8 miles) a day, 6 or 7 days a week. Distance swimmers may double that distance. This distance equates to 16,000 shoulder revolutions per week, or approximately 2,500 revolutions per day. Many of these revolutions are done in sequence, without any rest for the muscles to recover. It has been calculated that the average freestyle swimmer performs almost 400,000 strokes per arm per year, women 660,000 because they require more strokes to swim the same distance. Symptoms increased with the caliber of the athlete, were more common in the early and middle portions of the season, and were often exacerbated by the use of hand paddles during training.

The major cause of shoulder pain is an "impingement syndrome" between humeral head and rotator cuff on the coracoacromial arch. The sports medicine literature often refers to "swimmer's shoulder," an ill-defined condition that is widely synonymous with impingement syndrome and rotator cuff tendinitis (Fig. 7.2). Swimmer's shoulder pathology could involve a more complex pattern of lesions that follows repeated microtrauma and overuse strain of static and dynamic stabilizer of the shoulder. Diminished performance over a period of time (overuse) can sometimes lead to an acute injury, resulting in reduced ability or an inability to participate in the sport [2, 8].

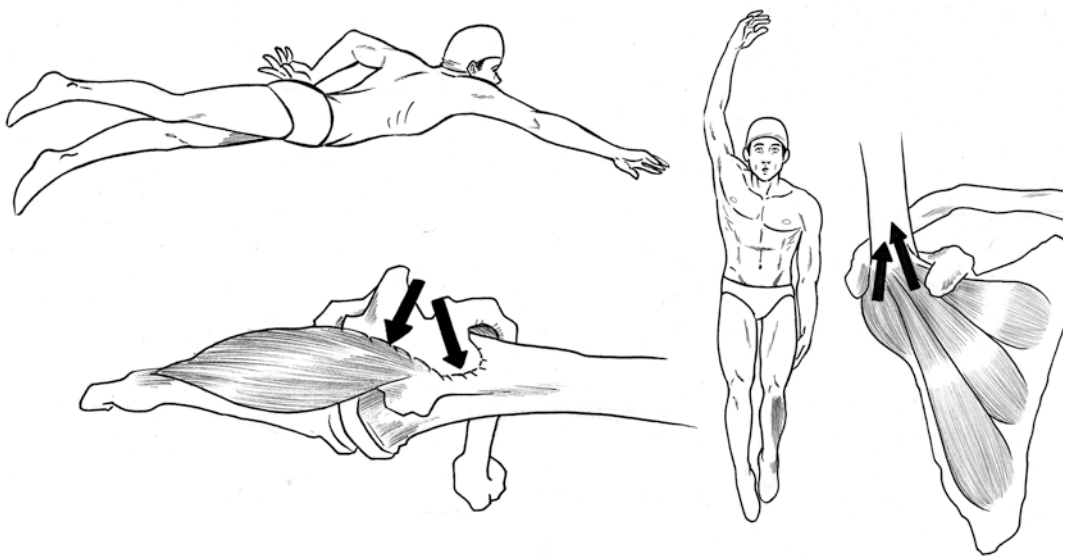

Fig. 7.2 Swimmer's shoulder. Pull-through phase: mechanism of impingement between humeral head and rotator cuff. In the backstroke, the initial phase of pull-through phase will be a tendency to place tension on the anterior part of glenohumeral capsule (*arrows*)

Gymnastic: Gymnastic events produce unique forces across the shoulder. Rather than performing motions repetitively, the gymnast often has to maintain one position for relatively prolonged period of time. In male gymnast who performs extensively on the rings, which produce a great deal of stress across the shoulder, a benign cortical hypertrophy often develops at the insertion of the pectoralis major muscle into the proximal humerus. This has been termed by Fulton the "ringman's shoulder lesion" [9]. In a study of female gymnast by Snook, the second most common injury was a supraspinatus tendinitis, which emphasized the great degree of tension and compressive forces about the shoulder that occur with gymnastics [10].

7.2.2.1 Baseball and Throwing Athlete

The act of throwing is one of the fastest and most violent maneuvers to which any joint in the body is subjected. For each pitch, the thrower must generate high levels of energy in the lower extremities and trunk to accelerate the ball to top velocity. The muscles and capsular structures of the shoulder must then dissipate this force after ball release and during arm deceleration. In elite pitchers, internal rotation of the humerus can reach velocities as great as 7,000 deg/s. To maximize the force that can be generated and transferred to the ball, the structures of the shoulder must strike a delicate balance between adequate laxity to achieve extreme range of motion and sufficient stability to inhibit subluxation and instability. This delicate equilibrium has been referred to as the "throwers paradox." At the extremes of motion, the forces generated and the speed with which this motion occurs, place the stabilizing structures of the glenohumeral joint and scapula at risk [11].

Most studies demonstrated that at least 50 % of all players experienced shoulder pain at some point during the athletic season [12]. There are multiple causes of shoulder pain in overhead throwing athletes including Little League shoulder, rotator cuff injury, glenohumeral instability and glenohumeral internal rotation deficit (GIRD). Most shoulder injuries are due to chronic stress placed on the skeletally immature shoulder during repetitive throwing activities. These injuries occur in greatest frequency during the mid- to late teen years as the shoulder is subjected to progressively higher stresses with increasing muscular development.

The importance of core activation in initiating this kinetic chain of events has been advocated as an etiologic factor that leads to shoulder pain in more immature pitchers.

Children without injury throw with mechanics similar to adults but with several important differences. When comparing Little League to college and professional pitchers, the younger Little League pitchers generate slower trunk and hip rotation and shoulder external rotation velocities. In addition, their elbow may fall behind their body in the cocking phase and with overall poor synchronization of arm motion with body motion. These improper mechanics can lead to increased stress on the shoulder with a higher risk of injury [2, 12, 13].

Little League shoulder: Little League shoulder is an apophysitis caused by repetitive rotational stresses on the proximal humeral physis during overhead throwing activity. The injury is typically seen in baseball pitchers between 11 and 13 years of age when physeal growth is maximal.

Radiographs reveal widening of the proximal humeral physis, which may be subtle and require comparison views of the contralateral shoulder to detect. There may be associated fragmentation, sclerosis, demineralization, and cystic changes of the humeral physis. Since Little League shoulder is primarily a clinical diagnosis, magnetic resonance imaging (MRI) is rarely used to evaluate patients with suspected apophysitis. However, MRI may show widening and edema within and around the proximal humeral physis [14, 15].

The goal of therapy for the thrower who presents with shoulder pain is to develop a straightforward rehabilitation program. For an injured athlete, rest and recovery of range of motion is the first step. In an effort to decrease the number of youth overuse injuries, Little League Baseball and the American Sports Medicine Institute have recommended pitch count limits and appropriate number of rest days between pitching appearances. The days of rest required between appearances increases with player age and number of pitches thrown [2, 15]. The next goal is to improve muscular strength and endurance. Resistance is initially light with an emphasis on form. Volume is progressively increased. Once adequate endurance is obtained, the rehabilitation program focuses on strength and speed. It is important to train muscles to respond and contract at a speed that is consistent with performance speed. Once motion and strength with endurance is regained, the thrower begins a progressive throwing program.

The coordinated production and transfer of potential energy from the body to the upper extremity in the form of kinetic energy is required to propel the ball at top velocity. Continuative program of education of gesture with emphasis on proper throwing mechanics and control rather than speed is the key to lead to fewer future shoulder injuries. A coordinated approach among trainers, therapists and physicians is required for the comprehensive evaluation, diagnosis, and treatment of shoulder pain in the throwing athlete.

Finally, shoulder pain in young overhead athlete could be a consequence of the only referred glenohumeral pain even very rare in younger athletes. Repetitive stress may injure the AC and sternoclavicular joints (SCJs). Finally, less common causes of shoulder pain in the throwing athlete should be borne in mind. These include quadrilateral space syndrome, suprascapular nerve entrapment, axillary artery occlusion, axillary vein thrombosis, posterior capsule laxity, and glenoid spurs.

7.2.2.2 Glenohumeral Internal Rotation Deficit

Glenohumeral internal rotation deficit (GIRD) is defined as a condition resulting in the loss of internal rotation of the glenohumeral joint as compared to the contralateral side. Changes to the dynamic restraints of the glenohumeral joint caused by repetitive stress are found in most overhead athletes, especially younger ones; changes to the internal rotator cuff musculature have been documented in young swimmers and baseball and tennis players. A GIRD occurs primarily in overhead athletes often seen in baseball pitchers. A number of theories have been reported concerning a time line for developing GIRD, and the underlying etiology of these adaptations is controversial.

Glenohumeral internal rotation deficit occurs before any other motion adaptation and is sometimes followed by associated gains in ER. Contractures of the posterior capsule and tightening of the large anterior shoulder muscles are to blame for some of this change in motion. GIRD begins in the early years with a bony adaptation of the humerus. Higher humeral head retroversion, found in both Little League and college-age baseball players, have been attributed to the quick change in velocity during the late cocking-through-deceleration phases of the throwing motion [16]. IR alterations have also been documented in adult and college-age swimmers and adolescent tennis players as a consequence of soft tissue changes, static and dynamic stabilizers. If not detected, GIRD tends to worsen over time and ultimately alters normal scapular and shoulder biomechanics.

First line of treatment in younger athletes is rest from throwing and physical therapy for six months which include posterior capsule stretching (sleeper stretch) performed with internal rotation stretch at 90° of abduction with scapular stabilization, pectoralis minor stretching, subscapularis and serratus (anterior) strengthening. Although very uncommon in the adolescent population, operative treatment with posterior capsule release or anterior stabilization is required only if extensive physical therapy fails [17].

7.2.3 Capsuloligamentous Injuries

7.2.3.1 Glenohumeral Instability

Pediatric shoulder instability continues to be a significant clinical problem. It is a more commonly encountered shoulder problem in young overhead athletes. Traumatic dislocation of the shoulder in childhood is rare, accounting for only 0.01 % of all injuries in this age class. Depending on age, joint injuries in children and adolescents far more commonly result in metaphyseal fractures than in injuries to the joint capsule, ligament disruptures, and dislocations.

More than 50 % of the dislocations occurred during sporting activities. Ninety-three percent of the casualties were aged over 10 years, and 62 % were female (Fig. 7.3). Only about 4 % of all dislocations of the shoulder affect patients in whom the growth plates are still open [18].

Glenohumeral instability is often characterized as traumatic or atraumatic. As in adults, 8 traumatic anterior dislocations account for 90 % of cases, usually following a fall onto the abducted, externally rotated arm; traumatic posterior dislocations are rare and reported only anecdotally [19].

Closed reduction under conscious sedation is often necessary and a post-reduction immobilization is mandatory. In the first time dislocation this could be a definitive choice of treatment unless there are some risk factors or complex articular joint tears that need an acute surgical treatment. The type of treatment by post-operative sling may be important. There has been growing interest in whether immobilizing the upper extremity in external rotation has an effect on treatment efficacy [20, 21].

Fig. 7.3 Radiograph in an AP view shows first-time anterior dislocation of the glenohumeral joint

Despite a number of publications regarding this topic, there is a paucity of comparative studies to review as a basis for clinical decision-making. A Level II evidence exists to support the conclusion that post-reduction immobilization in external rotation may reduce recurrence, while Level I evidence suggests that immobilization in internal rotation does not reduce recurrence. A recent Cochrane review on this topic could only find one "flawed quasirandomized trial" comparing post-reduction immobilization in external rotation to immobilization in internal rotation [22]. No significant differences in terms of return to activity or recurrent instability or dislocation were found and similar numbers of patients discontinued their immobilization within 1 week of treatment in both treatment arms [20].

There is a paucity of literature regarding the outcome of skeletally immature patients who sustain a primary traumatic anterior shoulder dislocation [23]. Most published results focus on adolescents and young adults, using recurrent dislocation/instability as a determinant of outcome rather than a validated quality of life measurement tool. As early as 1956, Rowe [24] demonstrated a 100 % risk of recurrence if the patient sustained a primary dislocation before age 10 years. Another study by Marans et al. [25] also reported a 100 % rate of redislocation in 21 adolescent patients with open physis who sustained a traumatic anterior dislocation. However, these two studies did not report on the functional outcome of these patients.

Presently, isolated outcome data are limited regarding primary traumatic anterior shoulder dislocation in the skeletally immature pediatric population. Therefore, there is a lack of consensus for the ideal treatment of such a patient. Although an abundance of data exists on dislocation in a mixed population of adolescent and young adult patients, caution should be taken in extrapolating such data to the pediatric skeletally immature patient.

An important aspect to define is if dislocation occurs with a pathoanatomical tears of capsulolabral complex or only with their enlargement due to the congenital laxity or intrinsic characteristics of collagen. This lends credence to the idea that, regarding shoulder instability, children are not simply "little adults." The primary pediatric traumatic shoulder dislocation represents a distinct pathoanatomical entity. It has been hypothesized that the capsular structures of the pediatric shoulder have a much greater elasticity than their adult counterparts [26]. This finding, theoretically, would allow for a resilient shoulder that is resistant to structural damage. In addition, it is believed that a more laterally based capsular insertion on the glenoid in the pediatric skeletally immature patient would create a smaller anterior/inferior recess, as described by Rockwood and Matsen [22]. This would impart increased tension on the anterior capsule when healed, making recurrent instability less likely in the younger pediatric population. The high variable rate in recurrent dislocation after first-time dislocation reported in the literature is thus explained.

About the debate on conservative versus operative treatment of traumatic shoulder instability, there is a void in the data available, and it is unknown how patients present and how they respond to treatment. It is unclear whether children are similar to adult patients with the same diagnosis or whether they require different treatment, in the same way that certain pediatric fracture patients require different management than adult fractures at the same anatomic sites. The concerns with traumatic dislocations include the risk of recurrent instability and the right treatment of associated secondary injuries of the humeral head, articular cartilage, anterior and posterior capsule, glenohumeral ligaments and glenoid and biceps tendon.

The prevalence of dislocations in patients younger than 18 years is 19.7 in 10,000 for men and 5.01 in 10,000 for women. Age at the time of the initial dislocation is inversely related to the recurrence rate: Recurrent dislocation is higher in patients younger than 18 years old and in men. The presence of bony lesions has a dramatic impact on surgical outcome, as athletes participating in contact sports are at a higher risk of recurrence.

The arthroscopic treatment for traumatic shoulder instability in young athletes has recently become the best option for the majority of surgeons due to improvements in suture anchors and cosmesis as well as the possibility of identifying and treating additional intra-articular lesions such as HAGL, SLAP or posterior Bankart lesions. Studies comparing nonoperative treatment with immediate open or arthroscopic Bankart repair for initial traumatic anterior dislocations demonstrated a lower recurrence of dislocation after the surgical procedure with recurrence rates of 3–19 % [2, 27].

The major disadvantage of arthroscopic Bankart repair is still the rate of recurrence, even if recent studies have shown better outcome and lower recurrence rate [28].

Ligamentous laxity in young athletes can lead to atraumatic or multidirectional shoulder instability, especially in throwers, gymnasts, and swimmers. It results from chronic overload owing to excessive repetitive external rotation during overhead motion with high stresses on the anterior capsuloligament restraints. Patients with hyperlaxity often experience subluxation episodes with spontaneous reduction and reveal evidence of hyperlaxity of multiple joints. In contrast to surgery for traumatic dislocations, a specific rehabilitation program, often up to 6 months, is successful in more than 80 % of those with multidirectional instability [2, 28].

Since the introduction of arthroscopic techniques for refixation of the anterior labral complex using suture anchor systems, which are generally absorbable, this technique is the gold standard for surgical treatment of post-traumatic, recurrent, anterior shoulder instabilities, but arthroscopic labral refixation is suitable only for the small number of children and adolescents, suffering from post-traumatic shoulder instability (Fig. 7.4). The advantage of surgical treatment is not undisputed, and even current literature has nowadays no consensus about the right treatment revealing redislocation and instability rates of up to 20 % in longer follow-up periods of almost 100 months following arthroscopic surgical treatment. Five percent of redislocations are described even with

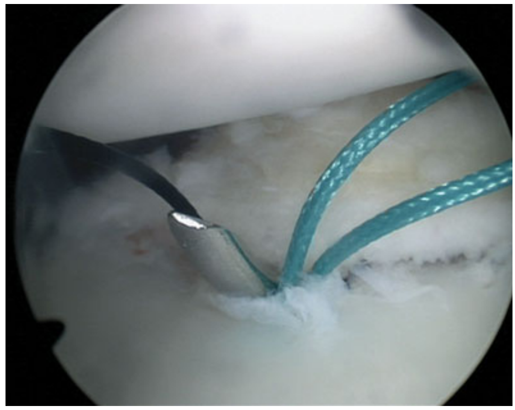

Fig. 7.4 Arthroscopic view. Traumatic labral injury with multidirectional instability in a 16-year-old high-performance basket player with labral refixation suitable only for the small number of young athletes, suffering from post-traumatic shoulder instability

immediate arthroscopic refixation of the labral complex after traumatic first dislocation [29].

The first rigorous differentiation must be made in this assessment regarding the laxness of the shoulder joint, which may vary greatly from one case to the next and regarding habitual shoulder joint instability, which is generally multidirectional. Early surgical stabilization has the advantage of a significantly lower recurrence rate for young active patients. However, early surgical intervention will result in some patients having unnecessary surgery, and further research is needed to establish prognostic factors that can stratify patient risk in order to identify individuals most likely to benefit from surgery. Patient age at first-time dislocation is clearly an important prognostic factor, but other issues, particularly patient activity level and specific sport participation, may provide further prognostic value to help determine which patients would benefit from early surgical intervention.

Arthroscopic labral refixation is a reliable, surgical treatment procedure, and it can be used successfully in children and young people prior to skeletal maturity. No alteration of the surgical procedure of Bankart repair in adults is necessary. Furthermore, arthroscopic stabilization using suture anchors appears to be comparable to open stabilization although, again, there may be certain subsets of patients, for example contact athletes, who would benefit from open stabilization.

7.2.3.2 SLAP Lesions

To understand the etiology of superior labral injuries, it is useful to first consider the two discretely different mechanisms of injury that have been proposed in the literature: superior compression and inferior traction. An acute traumatic superior compression force to the shoulder, usually due to a fall onto an outstretched arm with the shoulder positioned in an abducted and slightly forward-flexed position at the time of impact, was the most common mechanism of injury described. The throwing athlete appears to be prone to this mechanism. Both biomechanical and clinical explanations exist for the occurrence of SLAP lesions in overhead athletes. Large forces in the biceps tendon during the deceleration phase of the throwing motion may create SLAP lesions.

The diagnosis of SLAP tears can be difficult as they often coexist with other injuries. The clinical presentation of superior glenoid lesions is quite variable. A review of the literature does not identify a specific constellation of historical or physical findings that are pathognomonic for superior glenoid lesions.

Throwers may or may not relate a specific event to the onset of symptoms, and they will complain of an insidious onset of nonspecific shoulder pain, often occurring in the overhead position.

The value of imaging studies has been questioned in the orthopedic literature, in which detection of superior glenoid disease has been reported in only 9–38 % of cases. Plain radiographs cannot identify a SLAP lesion, but assessment of the acromial morphology and the AC joint is useful in considering associated disorders. The utility of MRI or computer tomography arthrograms for diagnosing this lesion is touted in the radiology literature. Recent data suggest that a 3T magnetic resonance arthrogram is the most sensitive study for the diagnosis of SLAP tears [2, 30]. Among the four main types of SLAP tears, Type II is most common in throwers.

Most adolescents with a suspected superior labral lesion should undergo a period of conservative management, including rest, physical therapy, and rarely nonsteroidal anti-inflammatory drugs.

Despite the efforts to make the diagnosis preoperatively, most lesions are discovered and treated surgically at the time of arthroscopic diagnosis. Shoulder arthroscopy should be considered if symptoms do not improve after a correct rehabilitation program. Type I lesions require only debridement of the frayed labral edge. Type II lesions are most common and are best treated with suture anchor or biodegradable-tack fixation of the unstable biceps anchor. Type II lesions should be treated with debridement of the bucket-handle portion of the superior labrum. Finally, Type IV lesions may require debridement of the torn portion of labrum and biceps tendon, arthroscopic repair and stabilization, or biceps tenodesis, depending on the amount of biceps tendon involvement (Fig. 7.5). Controversial results regarding SLAP repairs are reported in the literature with different impairments of the return to their preinjury level. Oh et al. [31] published their results of 34 patients undergoing arthroscopic repair of isolated SLAP

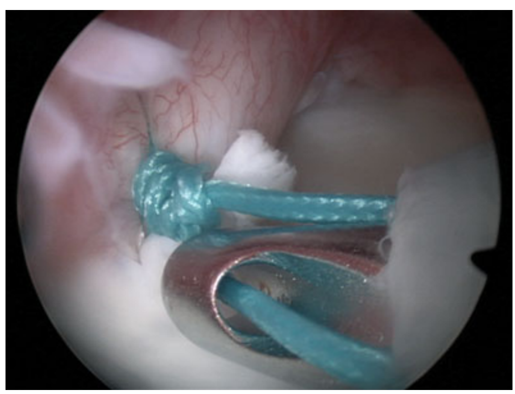

Fig. 7.5 Arthroscopic SLAP repair using suture anchor systems, which are generally absorbable. Labral debridement or repair depend on the type of tear found at surgery. Surgical technique is similar to that used in adults

tears using suture anchors [2]. At 33 months post-surgery only 22 % of those involved in overhead sports returned to their preinjury level without any limitations. This is in contrast to 63 % of those in nonoverhead sports activity.

7.2.3.3 Rotator Cuff Injuries

In the pediatric and adolescent population the overall incidence of rotator cuff injury is rare, with only small case series present in the literature. Although these injuries in children are relatively rare, their presence both in isolation and with other associated pathology must be recognized.

Furthermore, health care providers caring for adolescent athletes with shoulder pain must be able to identify the source of pain to prescribe the appropriate treatment. Frequently, these younger patients have a constellation of findings suggesting the diagnosis of internal impingement. First described by Walch et al. [32] in 1992, the concept of internal impingement has been well studied in adults. However, its presence in adolescents is not well characterized. Several theories exist as to the fundamental cause of the pathology, but the ultimate lesion often involves both posterior and posterosuperior glenoid labral tears and an articular-sided rotator cuff tear in an overhead athlete.

In addition, some authors suggest that anterior instability plays a significant role in the disease process, with increased anterior humeral head translation being the underlying process that leads to the posterior labral tears and P.A.S.T.A. (Partial Articular Sided Tendon Avulsion) lesions seen in these patients [33].

Furthermore, Eisner [34] reported a hypertrophic synovitis lesion in the posterosuperior region in addition to a P.A.S.T.A. lesion. Although this lesion has not been previously described, its presence may be within the spectrum of internal impingement in adolescents, representing a synovial response to increased contact between the humeral head and posterosuperior joint capsule and adjacent structures.

Treatment of rotator cuff pathology in adolescent patients generally begins, and is almost always conservative, with a course of physical therapy. If symptoms persist, surgical intervention may be warranted. Shoulder arthroscopy allows the treating surgeon to address the rotator cuff and associated capsulolabral, biceps or cartilaginous pathology, simultaneously. However, the outcomes of both conservative and surgical treatment of rotator cuff pathology in adolescent patients remain largely unknown [35, 36].

7.2.4 Upper Extremity Fractures and Joint Injuries in the Adolescent Athlete

7.2.4.1 Proximal Humerus Fractures

Most of proximal humerus fractures in adolescent are Salter Types I or II. Salter–Harris Type I physeal fractures occur primarily in neonates and children younger than 5 years old. Children aged between 5 and 11 primarily have metaphyseal fractures, whereas those older than 11 have Salter–Harris Type II injuries. Traditionally, pediatric proximal humerus fractures have been treated nonoperatively. This is because roughly 80 % of the longitudinal growth of the humerus occurs at the proximal humerus; therefore, there is great potential for remodeling at this site. Furthermore, the large arc of motion of this joint can compensate for a large degree of malunion and angulation. Accidentally, pathologic bone lesions such as unicameral bone cysts are found in up to 25 % of adolescents with proximal humerus fractures [2].

The correct treatment of fractures of the proximal humerus in children and adolescents depends on the fracture location, degree of displacement, and the child's age. Conservative treatment by a shoulder sling is the gold standard for no displaced or minimally displaced fractures. Because of the high potential of spontaneous correction due to the proximal humeral epiphysis the prognosis of proximal humerus fractures is good. Till the age of 12 years, a correction of 50–60° of shaft breaks in the frontal and sagittal planes is possible by a closed reduction. We recommend an immobilization for 3–4 weeks if the fracture is stable after closed reduction.

Beyond the age of 12 years the correction ability shrinks to half of the primary malposition, which can be tolerated to a maximum of 40 degrees of correction [2].

More frequent fractures that need a surgical fixation in adolescents are Salter–Harris Type II fractures, which entail a more proximal fracture line with a steeper angle compared with fractures in adults. This translates into a different pin configuration as well as a different reduction maneuver. There are a lot of many pin configurations, but it is important to emphasize that the goal with each of these pin patterns could be a perfect balance between fixation into the humeral shaft and humeral head, optimization of the biomechanical trajectory across the fracture line. No skeletal complications are rarely reported with injuries in this area. Transient axillary nerve paralysis has been described. Usually, however, these problems resolve by the time the athlete is ready to start the recovery or rehabilitation phase.

Brachial plexus paresis as well as complete disruption of the brachial artery is a very rare event and reported in the literature only as case reports.

7.2.4.2 Clavicle Fractures

Clavicle fractures are frequent injuries in young athletes due to its superficial location, its thin midshaft, the forces transmitted across it, but also the prominent use of the shoulder girdle during many athletic feats in different sports, like blocking and tackling in football as well as battering ram in hockey or rugby. Clavicle fractures comprise up to 15 % of all fractures in this population.

The anatomic site of the fracture is typically described using the Allman classification, which divides the clavicle into thirds: Group I (midshaft) fractures occur on the middle third of the clavicle, group II fractures on the lateral (distal) third, and group III fractures on the medial (proximal) third.

Midshaft fractures account for approximately 75–80 % of all clavicle fractures and typically occur in younger persons. Distal third fractures represent about 15–25 % of clavicle fractures. Medial third fractures are least common, accounting for less than 5 % of clavicle fractures.

The pediatric athlete usually has a distinct history of injury when a clavicular fracture is present. They typically hold the affected arm adducted close to the body, often supporting the affected side with the opposite hand. This position is most comfortable because it limits the pull from the weight of the arm on the fractured bone. Physical examination may reveal ecchymosis, edema, focal tenderness, and crepitation on palpation over the clavicle. The defect in the bone may be seen by visual inspection or localized by palpation. Despite the low incidence of complications, it is important to perform a neurovascular and lung examination, because the subclavicular vessels, brachial plexus, and lung apex can be injured in posteriorly displaced fractures.

Radiography should be performed on all patients with suspected clavicle fractures. Most fractures can be seen on a standard anteroposterior view of the clavicle; however, an anteroposterior view with 45° cephalic tilt minimizes the overlap of the ribs and scapula and allows for better assessment of displacement in the anterior and posterior plane [37]. Advanced imaging such as computer tomography is indicated only in rare cases of distal or proximal fracture to assess the extent of intra-articular involvement.

Consideration of anatomy within the area of the fracture is essential so that associated injuries can be diagnosed and appropriately treated. A standard sling or a “figure-of-8” brace, when the latter would not cause complications such as compression of axillary vessels and brachial plexopathy, is the gold standard treatment for nondisplaced or minimally displaced fractures in patients of all ages.

We would recommend that displaced fractures with or without compromised skin integrity, associated neurovascular injury, and floating shoulder must be performed by surgical approach. Open reduction internal fixation of significantly shortened or displaced fractures in skeletally immature adolescents or teenagers to improve time to union and decrease the incidence of symptomatic malunion [38]. Return to sporting activity is frequently quicker in such operatively treated patients. Patients usually can return to noncontact sports and full daily activities six weeks after injury. Contact and collision sports should be delayed for two to four months until solid bony union occurs. If surgery is performed, some surgeons recommend removal of hardware before returning to sports. However, plate removal may delay return to sports and is not recommended by other surgeons [2, 39].

7.2.4.3 Acromioclavicular Joint Injuries

Acromioclavicular joint injuries occur as a result of a direct force applied to the tip of the shoulder or due to indirect trauma such as a fall on the outstretched hand. These mechanisms lead to bone injuries in younger adolescents, while they lead to the AC sprain in the older ones.

Acromioclavicular joint dislocations range from a simple sprain of the acromioclavicular and coracoclavicular ligaments to widely displaced injuries with dislocations of the distal third of the clavicle.

Acromioclavicular dislocations are classified on the basis of the radiographic findings. X-ray includes a standard shoulder view or sometimes an additional "Zanca view," consisting of AP view with a 10° of superior tilt. Different classification systems are available, being that of Rockwood the most widely utilized. This classification takes into account not only the position of AC joint, but also the coracoclavicular ligament, the deltoid and trapezius muscles, and the direction of dislocation of the clavicle with respect to the acromion.

Type I injury is a partial tearing of the AC ligament but with the joint remaining intact. Type II injury is a complete disruption of the AC ligament, while the coracoclavicular ligaments are not completely disrupted. Type III injury results in a 25–100 % superior displacement of clavicle (a dislocation) as the AC and coracoclavicular ligaments are both completely disrupted. Rockwood then further delineated variations of the Type III as IV, V, and VI where the clavicle is captured by other soft tissues [40].

The majority of AC joint injuries are successfully treated nonoperatively with a period of sling immobilization followed by progressive physical therapy and shoulder range of motion exercises. Surgical management of AC joint injuries is indicated in Types IV, V, and VI injuries and in very selected cases, Type III. Many surgical techniques described in the literature involve the use of metallic implants for internal fixation or reconstruction of the CC (Coraco-Clavicular) ligament by transferring the AC ligament or using autograft or allograft tissues [2, 41].

7.2.4.4 Sternoclavicular Joint Injuries

Sternoclavicular joint (SCJ), like the AC joint, can suffer a spectrum of ligamentous injuries, even rare in the adolescent athlete. When it comes to dislocation, it can dislocate anteriorly or posteriorly, depending on the different mechanism of injury occurring during the sport event. The posterior structures are stronger than the anterior and this is why posterior SCJ dislocations are rarer than anterior dislocations. The key to diagnosis is a detailed patient history and physical examination, but in most cases occurs only a slight or none deformity. Nevertheless, before CT scan evaluation became possible, such injuries were often discovered very late.

Anterior dislocations are often successfully treated with closed reduction. Posterior dislocations have significant clinical implications because of the proximity of surrounding vessels and nerves, trachea, and esophagus. Any attempt at reduction in a posterior dislocation compressing the mediastinal structures requires the presence of a cardiothoracic surgeon. Patients with posterior dislocations are usually stable after reduction, and surgery is required only if a redislocation occurs or if there is symptomatic instability.

Many surgical procedures have been advocated for SCJ dislocation such as Kirschner wires or Steinmann pin fixation, polydioxane cords or custom-made plates. Arthrodesis of the SCJ is also contraindicated because of the marked restriction in shoulder movement which it produces. More recently, Bae reported satisfactory results with the use of a semitendinosus tendon graft in a figure-of-8 fashion through drill holes in the sternum and manubrium [42].

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