Shoulder injuries in skeletally immature throwers: review and current thoughts

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Shoulder injuries in skeletally immature throwers: review and current thoughts

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ABSTRACT

The incidence of shoulder injuries in the paediatric athletic population continues to increase with increased participation particularly in throwing and overhead sports. While soft tissue injuries can occur, the physis remains the weak link and site of injury in many cases. Injury prevention targets proper throwing mechanics and the avoidance of overuse injuries by monitoring the amount of training and number of throws these young athletes are exposed to.

The incidence of shoulder injuries in the paediatric population is increasing as participation in recreational and competitive leagues grows. These injuries are caused by either an acute traumatic event or, more commonly, chronic overuse from repetitive overhead motion. Rather than the soft-tissue or ligamentous injuries commonly seen in adult shoulder injuries, the weak link affected in paediatric shoulder pathology tends to be the developing physis. Combined with continued development of strength, coordination and physical skill, the paediatric shoulder offers distinctive challenges to the sports medicine physician.

DEVELOPMENTAL ANATOMY

Proximal humerus

The proximal humerus consists of three ossification centres: the humeral head, the greater tuberosity and the lesser tuberosity (figure 1). By 5–7 years of age, these centres combine to form a single proximal humeral epiphysis. This physis contributes 80% of the longitudinal growth to the shoulder, allowing for a significant amount of growth and remodelling. Fusion of the humeral epiphysis to the shaft occurs between the ages of 14 and 17 years in girls and 16–18 years in boys.[1 2]

Clavicle

The clavicle consists of a lateral and medial ossification centre (figure 2). The medial ossification centre provides 80% of the longitudinal growth to the clavicle, and is one of the last physes to close in the body, sometime between the ages of 22 and 25 years.[2] The lateral ossification centre is rarely identified radiographically, as it ossifies and fuses over a period of a few months at approximately 19 years of age.[3] Identification of this physis is often confused with a fracture.

Scapula

The scapula consists of several ossification centres that are highly variable in terms of number and position (figure 2). The coracoid process consists of two to three ossification centres that first appear at 1 year of age and fuse by the age of 15–16 years. An ossification centre at the tip of the coracoid process sometimes appears and fails to fuse, being misinterpreted as a fracture. The acromion consists of two to five ossification centres that appear at puberty and fuse at approximately 22 years of age. Failure to fuse of these acromial physes has been termed an 'os acromiale' and can lead to pain in the mature athlete. The glenoid fossa consists of two ossification centres, and the vertebral border and inferior angle of the scapula each contain one. These centres typically appear around puberty, fusing by 22 years of age.[2]

ACUTE SHOULDER INJURIES

Traumatic injuries to the shoulder (fractures and dislocations) have a very low incidence; however, their frequency is relatively more common during athletic activities.[4] The mechanism of injury usually involves a forceful collision, fall onto an outstretched arm, or a sudden wrenching movement. The resultant injury most commonly is a glenohumeral dislocation, although fractures of the clavicle and proximal humerus also occur.

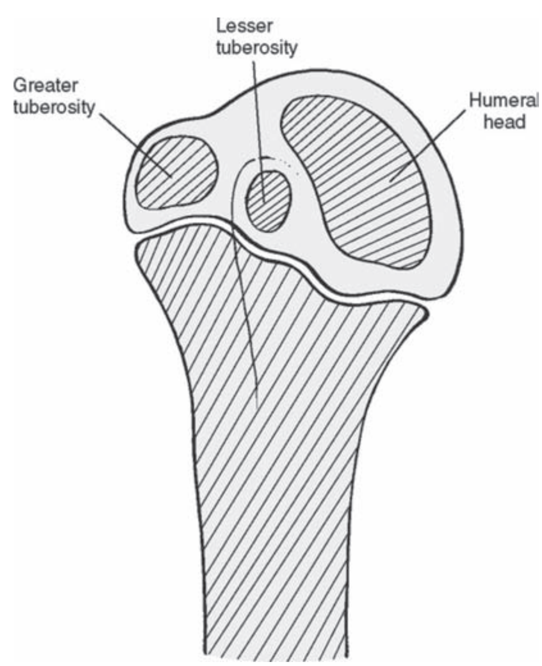

Figure 1 Proximal humeral ossification centres. The humeral head ossification centre is usually identified after 6 months of age. The great tuberosity follows between 7 months and 3 years, and the lesser tuberosity between 2 and 5 years. These centres fuse between the ages of 5 and 7 years to compose the proximal humeral epiphysis. Reproduced with permission from O'Brien *et al*.[2]

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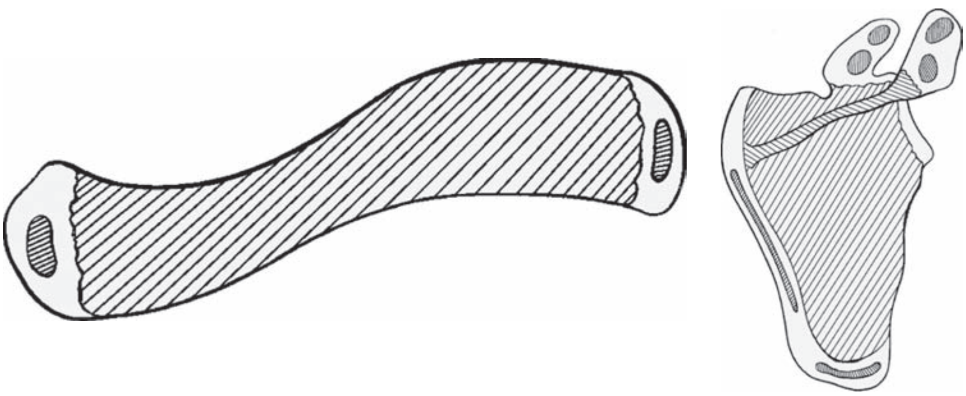

Figure 2 Left: Clavicle with medial and lateral ossification centres. Right: Scapular ossification centres identified on the vertebral border and inferior angle. Two ossification centres demonstrated on the coracoid process and acromion. A thirdossification centre can exist at the tip of the coracoids process. Not visualised are the two ossification centres of the glenoid fossa. Reproduced with permission from O'Brien SJ *et al*.[2]

Acute glenohumeral dislocation

Shoulder dislocations are a relatively infrequent injury in the paediatric population, but are more common in collision sports such as American football or rugby. Forty per cent of patients with primary shoulder dislocations are younger than 22 years.[5] Approximately 98% of these shoulder dislocations are anterior.[6] The diagnosis is confirmed with radiographs, including an anteroposterior, axillary and/or scapular-Y view of the shoulder. The tangential axillary view is essential and comparative views in the skeletally immature patient can be very helpful. Other modalities, such as magnetic resonance imaging or computed tomography, may be utilised to evaluate for associated soft tissue injuries, such as a Bankart lesion or labral pathology. In the paediatric population, most dislocations are intracapsular and have an associated capsular or labral detachment.[6]

Traditionally, treatment begins with non-operative modalities, including closed reduction, immobilisation in internal rotation with a sling and subsequent strengthening of dynamic shoulder stabilisers. Unfortunately, the recurrence rate of shoulder dislocations in the paediatric population despite adequate conservative therapy is very high: 83–90% in patients younger than 20 years,[6] and nearly 100% of patients with open physes[7] will have a recurrent instability episode. Relatively recently, studies have looked at immobilising patients in external rotation. Although biomechanical and cadaveric studies have shown improved bony apposition and healing in external rotation,[8–10] there are no level 1 and only a few level 2 evidence-based studies showing an improvement in recurrence rates[11] using immobilisation in external rotation. Perhaps the biggest challenge to the use of external rotation immobilisation is patient compliance. It is a particular challenge to maintain the paediatric population in this device for the required 6 weeks.

Surgical stabilisation procedures are indicated after the failure of non-operative treatment with recurrent instability. Due to extremely high recurrence rates, primary surgical stabilisation is gaining favour for young, active male patients with a dominant-side first-time dislocation. This is particularly true for those in the military population that participate in collision sports. Clinical results have shown a significant reduction of recurrence rates to 7–10% with surgical treatment.[12] Nonetheless, the indications for primary surgical stabilisation in the paediatric population have not been determined. Even with surgical stabilisation, patients with open physes appear to have an elevated risk of recurrence when compared with the same surgeries performed on patients with closed physes. Open stabilisation remains the gold standard, particularly for collision athletes,[13] but arthroscopic techniques are approaching the results of open procedures in most patients[1] and have potentially lower morbidity risks.

Clavicle fractures

Clavicle fractures account for 10–15% of all childhood fractures, mostly due to a fall directly onto the lateral aspect of the shoulder.[4] A majority of these fractures are mid-shaft, and are readily identifiable with plain radiographs. Prognosis for these fractures is excellent given the significant growth potential of the bone. Treatment is mainly symptomatic with a sling and the avoidance of sports for 6–8 weeks. The figure-of-eight brace has fallen out of favour because of greater discomfort without any improvement in outcome.[14] Surgical treatment is indicated for open fractures, neurovascular compromise and gross displacement with skin at risk of perforation.[15] More recently, the concept that the risk of non-union of a mild to moderately displaced clavicle fracture is negligible had been called into question and there is a growing trend to consider surgical reduction and fixation for more significant displacement regardless of the risk of skin perforation. Currently, there is no level 1 or 2 evidence-based literature to support this premise in the paediatric population.

Injuries to the sternoclavicular and acromioclavicular joints in the paediatric population are physeal injuries until proved otherwise. The medial clavicle physis is the last physis to close at 22–25 years of age. Ligaments attached to thick periosteum are significantly stronger than the physis, resulting in physeal fracture more commonly than dislocation. However, posterior dislocation of the sternoclavicular joint does occur in children, and should be ruled out with a computed tomography scan if clinical evidence suggests. Because of the remodelling potential, excellent results are achieved for medial and lateral physeal fractures with a sling and symptomatic treatment.[4]

Proximal humerus fractures

Athletic activities, in particular contact sports, account for 20% of proximal humerus fractures seen in the skeletally immature patient.[16] Salter–Harris type I fractures occur in neonates and children younger than 5 years, metaphyseal fractures between the ages of 5 and 11 years, and Salter–Harris type II fractures in adolescents older than 11 years.[4] Most injuries can be readily diagnosed with a radiographic series of the shoulder. Comparison views in the skeletally immature are strongly recommended.

Because of the tremendous remodelling potential of the proximal humerus, most authors do not recommend closed reduction or surgery for proximal humerus fractures regardless of the angulation or displacement in young patients.[4] However, older patients with less growth potential may need a closed reduction with significant displacement or angulation. Acceptable deformities in children older than 11 years are 50% displacement and less than 40° angulation.[17] Percutaneous pinning may be required if the fracture cannot be stabilised within this criterion. Rarely, closed reduction of these fractures cannot be achieved, mostly due to soft tissue interposition, requiring an open reduction and internal fixation.[18]

CHRONIC SHOULDER INJURIES

Participation in organised athletic activities has increased over the past three decades, with 45 million children and adolescents in the USA currently involved.[19] Concurrently, athletes are more commonly specialising in a specific sport at a younger age, with year-round training, simultaneous seasons and showcase events. Both trends have resulted in an increase in sports-related and chronic overuse injuries.[20] The incidence of shoulder pain in young baseball pitchers is 32%.[21] In addition, Dun *et al*[22] noted surgical treatment in high school baseball pitchers increased from 8% to 24% at his institution over the past 10 years. Although predominantly noted in baseball, these injuries are prevalent in other overhead sport activities including tennis, football, volleyball, cricket and swimming.

Biomechanics of pitching in paediatric throwers

Analysis of the baseball pitch demonstrates a significant amount of stress being placed on the shoulder, with an internal rotation torque of 67 Nm, an anterior translational force of 310 N and a compressive force of 1090 N (figure 3).[23] This stress, repeated with each subsequent pitch, markedly increases the risk of injury to the shoulder. In addition, the unique aspect of the paediatric skeleton alters the development and injury patterns to the shoulder. These features include joint laxity, underdeveloped musculature and open epiphyseal plates.

During the late cocking stage of pitching, the shoulder is in a position of maximal external rotation while the internal rotator muscles act on the proximal aspect of the humerus. The distal humerus and forearm lag behind the elbow, placing additional torque on the arm in maximum external rotation. These two opposing torques, the internal rotation of the proximal humerus and the external rotation moment of the distal humerus, produce a tremendous external rotation moment on the proximal humeral physis.[24] Occurring during a tremendous period of growth and development, this stress plays a major role in the maturation of the paediatric shoulder and the potential for injury.

Developmental changes to the shoulder in the paediatric thrower

The range of motion of the throwing athlete's shoulder adjusts in response to the extremes of motion seen with chronic overhead throwing. External rotation has been shown to increase by 10°, with a similar decrease in internal rotation and no change in the total arc of motion. This alteration is noticed as young as 8 years of age, and progresses until the closing of the proximal humeral physis.[25] Although originally thought to be a soft tissue effect, most authors agree the main cause is 'osseous remodelling'.[26] The large external rotation moment placed on the proximal humeral physis results in bony growth in the direction of humeral retroversion, as would be expected from Wolff's law. Evidence has shown a 14° and 17° increase in humeral retroversion when comparing the dominant versus non-dominant shoulder in professional handball[27] and baseball pitchers,[26] respectively.

These athletes are typically asymptomatic. In fact, some authors have described this rotational motion change as a beneficial adaptation.[24 26] The increased humeral retroversion allows increased external rotation with decreased tension being placed on anterior soft tissues. Decreased tension on the anterior constraints of the shoulder should decrease the chance of injury. Also, an increase in external rotation will allow an increased angle for which the ball can be in the acceleration phase, with a theoretical increase in pitching velocity. To date, no studies have been performed looking at humeral

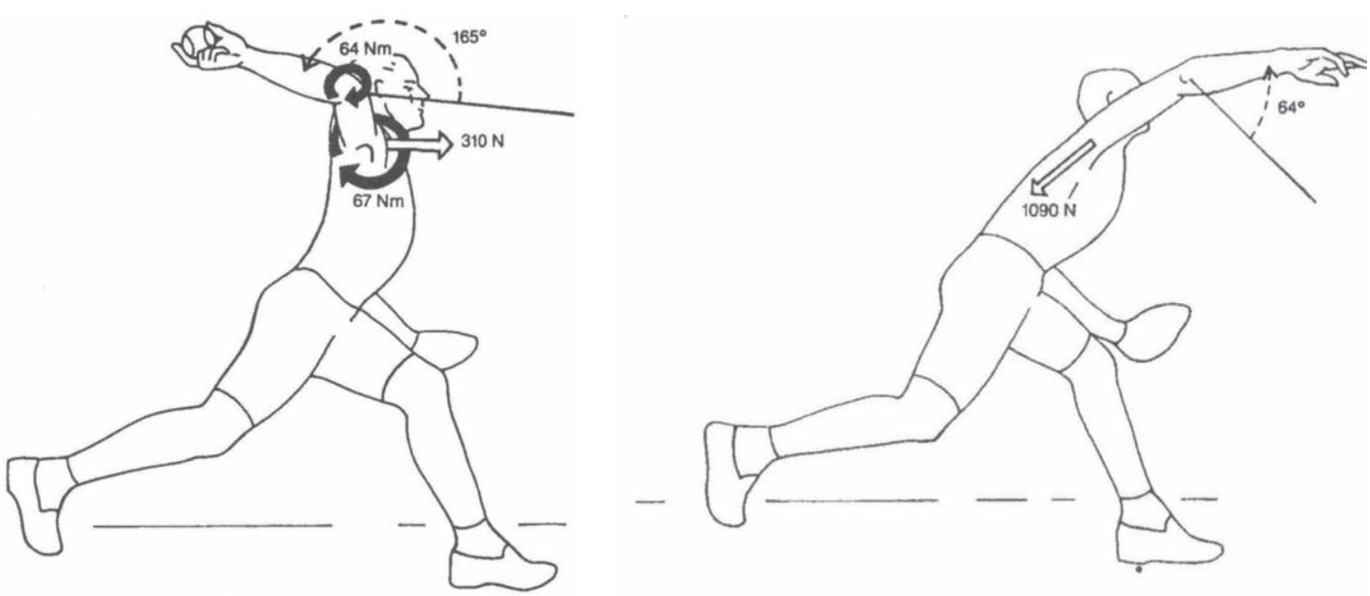

Figure 3 Left: Pitcher in the late cocking stage of throwing, near maximal external rotation. At this point, the shoulder is generating67 Nm of internal rotation and 310 N of anterior force. The forearm and distal humerus lag behind the elbow, leading to an external rotation torque being placed on the proximal humeral epiphysis. Right: Pitcher after acceleration and release of ball, in which the arm decelerates by producing a 1090 N posterior-directed force. Reproduced with permission from Fleisig *et al*.[23]

retroversion and its effects on the incidence of shoulder injury and pitching velocity.

Risk factors for shoulder pain

Several studies have identified a number of risk factors associated with shoulder pain in adolescent pitchers, including pitch counts, pitch types and pitch mechanics. Shoulder pain has been correlated with throwing more than 75 pitches in a game, throwing more than 600 pitches in a season and pitching with arm fatigue.[21 28 29] A prospective cohort study found a 52% increased risk of shoulder pain with throwing curveballs;[29] however, a more recent biomechanical study[30] found decreased moments on the shoulder when throwing a curveball versus a fastball. The authors hypothesised that shoulder pain is correlated with the velocity of the pitch rather than the pitch itself.[28] Poor pitching mechanics has been associated with shoulder injury; however, only one biomechanical study showing decreased humeral internal rotation torque and increased efficiency with proper mechanics has been described.[31]

Little league shoulder

Little league shoulder is an epiphysiolysis caused by the rotational stress placed on the proximal humeral epiphysis during overhead throwing. The growth plate is weakest to torsion stress, and is most susceptible to injury during periods of rapid growth commonly seen during puberty.[32] Most chronic shoulder injuries thus occur in throwing athletes between the ages of 13 and 16 years.

Patients typically complain of diffuse shoulder pain that is aggravated with throwing. History suggests a recent increase in their throwing regimen. Physical examination findings include tenderness and swelling over the anterolateral aspect of the shoulder, with weakness to abduction and internal rotation. The range of motion of the shoulder may show a decreased external and internal range of motion. Radiographic imaging will show physeal widening, and may show other signs such as metaphyseal sclerosis, osteopenia and fragmentation[33] (figure 4).

Treatment of little league shoulder involves rest and activity modification, followed by a progressive throwing programme. Patients should refrain from throwing until symptoms resolve, typically for a time period of 2–3 months. Throwing should then commence in a gradual fashion, with slowly increasing distance and velocity. Emphasis should be placed on appropriate pitching mechanics, as well as rotator cuff and periscapular strengthening and capsular stretching exercises. This protocol has shown excellent results, with 91% of patients remaining asymptomatic.[16]

Shoulder impingement

The extreme position of external rotation and abduction of the shoulder during maximal external rotation results in contact between the supraspinatus and the posterosuperior aspect of the glenoid and labrum. Overhead athletics, such as baseball, swimming and tennis, can cause injuries to the rotator cuff from this chronic impingement, such as tendinitis and partial rotator cuff tears. These injuries are more common in older, elite athletes,[34] but have been described in younger patients.[35]

Clinical features include anterolateral shoulder pain aggravated with activity, as well as weakness and stiffness. Physical examination should include active and passive range of motion, shoulder strength in addition to provocative impingement examinations such as the Neer and Hawkin's test. Radiographic evaluation of the shoulder will typically not reveal an abnormality, so a magnetic resonance imaging scan is often utilised to assess for any increased signal about the rotator cuff or its insertion into the greater tuberosity.

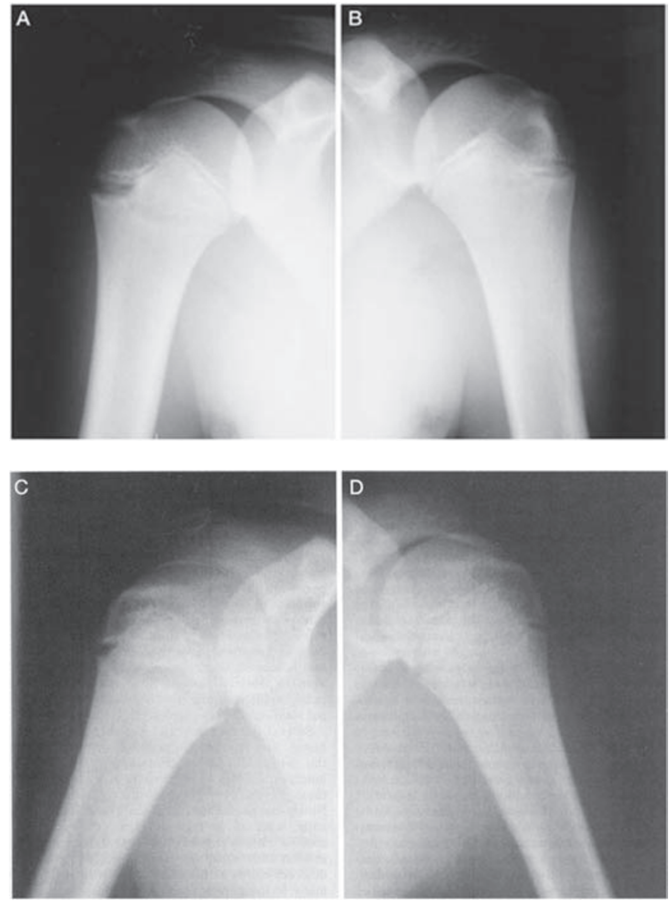

Figure 4 Radiographs of skeletally immature patients. (A and C) Physeal widening commonly seen in Little League Shoulder in internal and external rotation, respectively. (B and D) A reference for a normal appearing physis in a skeletally immature patient in internal and external rotation, respectively. Reproduced with permission from Carson *et al*.[33]

These injuries are treated conservatively with rest, ice and anti-inflammatory medication. Physical therapy focuses on stretching exercises to the posterior capsule, and strengthening of the rotator cuff and scapular stabilisers of the shoulder. For patients refractory to conservative therapy, arthroscopic debridement or repair of partial rotator cuff tears may be of benefit, although is rarely described.[16]

Prevention

Because of the high association of shoulder injury with pitches thrown, US baseball made a number of recommendations regarding pitches thrown and rest requirements for pitchers of all ages (tables 1 and 2). In addition, age restrictions were created for when young pitchers could start throwing certain pitches (table 3). Lyman *et al*[21] noted shoulder pain in association with showcases and pitching in multiple leagues, and stated that these types of events should be discouraged. Although no study shows a relationship, proper pitching mechanics should be emphasised at an early age.

Table 1 Maximum number of pitches recommended[36]

Age (years)	Maximum pitches/game	Maximum games/week
8–10	52±15	2±0.6
11–12	68±18	2±0.5
13–14	76±16	2±0.4
15–16	91±16	2±0.4
17–18	106±16	2±0.6

Table 2 Minimum number of pitches thrown that requires a rest[36]

Age (years)	1-Day rest	2-Day rest	3-Day rest	4-Day rest
8–10	21±18	34±16	43±16	51±19
11–12	27±20	35±20	55±23	58±18
13–14	30±22	36±21	56±20	70±20
15–16	25±20	38±23	62±23	77±20
17–18	27±22	45±25	62±21	89±22

Table 3 Age recommended for learning pitches[36]

Age (years)	Pitch type
8±2	Fastball
10±3	Change-up
14±2	Curveball
17±2	Screwball
16±2	Slider
16±2	Forkball
15±3	Knuckleball

CONCLUSION

Shoulder injuries, both acute and chronic, have increased as the popularity of recreational and competitive athletics has grown. Most acute shoulder injuries are caused by a traumatic fall while playing a sport. Because of the vast growth potential of the shoulder, most injuries are treated conservatively with excellent outcomes. The one exception has been the primary shoulder dislocation, which is seeing a trend towards surgical intervention to prevent the high recurrence seen in the paediatric population. Chronic shoulder injuries are caused by the tremendous rotational force applied to the growth plate repetitively during overhead throwing. Most of these injuries will resolve with activity and physical therapy. Moreover, most of these injuries can be prevented with appropriate guidelines regarding the number of pitches thrown, the age at which certain pitches are thrown and the limitation to only one league at a time.

Provenance and peer review Commissioned; not externally peer reviewed.

It is an honour to be part of this themed focus offering from BJSM which has brought together a who's who of contributors regarding shoulder issues in athletes.

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REFERENCES

1. **Chen FS**, Diaz VA, Loebenberg M, *et al*. Shoulder and elbow injuries in the skeletally immature athlete. *J Am Acad Orthop Surg* 2005;**13**:172–85.
2. **O'Brien SJ**, Voos JE, Neviaser AS, *et al*. *Developmental anatomy of the shoulder and anatomy of the glenohumeral joint*. In: Rockwood CA, Matsen FA, Wirth MA, *et al*, eds. *The shoulder*, vol 1. 4th edn. Philadelphia, Pennsylvania, USA: Saunders, 2009:1–31.
3. **Curtis RJ**. *Shoulder injuries: anatomy, biomechanics and physiology*. In: DeLee J, Drez D, Stanitski CL, eds. *Paediatric and adolescent sports medicine*. Philadelphia, Pennsylvania, USA: WB Saunders, 1994:183–90.
4. **Bishop JY**, Flatow EL. Paediatric shoulder trauma. *Clin Orthop Relat Res* 2005:41–8.
5. **Hovelius L**, Augustini BG, Fredin H, *et al.* Primary anterior dislocation of the shoulder in young patients. A ten-year prospective study. *J Bone Joint Surg Am* 1996;**78**:1677–84.
6. **Walton J**, Paxinos A, Tzannes A, *et al*. The unstable shoulder in the adolescent athlete. *Am J Sports Med* 2002;**30**:758–67.
7. **Marans HJ**, Angel KR, Schemitsch EH, *et al*. The fate of traumatic anterior dislocation of the shoulder in children. *J Bone Joint Surg Am* 1992;**74**:1242–4.
8. **Itoi E**, Sashi R, Minagawa H, *et al*. Position of immobilisation after dislocation of the glenohumeral joint. A study with use of magnetic resonance imaging. *J Bone Joint Surg Am* 2001;**83-A**:661–7.
9. **Miller BS**, Sonnabend DH, Hatrick C, *et al*. Should acute anterior dislocations of the shoulder be immobilised in external rotation? A cadaveric study. *J Shoulder Elbow Surg* 2004;**13**:589–92.
10. **Yamamoto N**, Itoi E, Abe H, *et al*. Contact between the glenoid and the humeral head in abduction, external rotation, and horizontal extension: a new concept of glenoid track. *J Shoulder Elbow Surg* 2007;**16**:649–56.
11. **Itoi E**, Hatakeyama Y, Sato T, *et al*. Immobilisation in external rotation after shoulder dislocation reduces the risk of recurrence. A randomised controlled trial. *J Bone Joint Surg Am* 2007;**89**:2124–31.
12. **Brophy RH**, Marx RG. The treatment of traumatic anterior instability of the shoulder: non-operative and surgical treatment. *Arthroscopy* 2009;**25**:298–304.
13. **Rhee YG**, Ha JH, Cho NS. Anterior shoulder stabilisation in collision athletes: arthroscopic versus open Bankart repair. *Am J Sports Med* 2006;**34**:979–85.
14. **Andersen K**, Jensen PO, Lauritzen J. Treatment of clavicular fractures. Figure-of-eight bandage versus a simple sling. *Acta Orthop Scand* 1987;**58**:71–4.
15. **Kubiak R**, Slongo T. Operative treatment of clavicle fractures in children: a review of 21 years. *J Pediatr Orthop* 2002;**22**:736–9.
16. **Kocher MS**, Waters PM, Micheli LJ. Upper extremity injuries in the paediatric athlete. *Sports Med* 2000;**30**:117–35.
17. **Dobbs MB**, Luhmann SL, Gordon JE, *et al*. Severely displaced proximal humeral epiphyseal fractures. *J Pediatr Orthop* 2003;**23**:208–15.
18. **Bahrs C**, Zipplies S, Ochs BG, *et al*. Proximal humeral fractures in children and adolescents. *J Pediatr Orthop* 2009;**29**:238–42.
19. **Goldberg AS**, Moroz L, Smith A, *et al*. Injury surveillance in young athletes: a clinician's guide to sports injury literature. *Sports Med* 2007;**37**:265–78.
20. **Caine D**, Caine C, Maffulli N. Incidence and distribution of paediatric sport-related injuries. *Clin J Sport Med* 2006;**16**:500–13.
21. **Lyman S**, Fleisig GS, Waterbor JW, *et al*. Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Med Sci Sports Exerc* 2001;**33**:1803–10.
22. **Dun S**, Loftice J, Fleisig GS, *et al*. A biomechanical comparison of youth baseball pitches: is the curveball potentially harmful? *Am J Sports Med* 2008;**36**:686–92.
23. **Fleisig GS**, Andrews JR, Dillman CJ, *et al*. Kinetics of baseball pitching with implications about injury mechanisms. *Am J Sports Med* 1995;**23**:233–9.
24. **Sabick MB**, Kim YK, Torry MR, *et al*. Biomechanics of the shoulder in youth baseball pitchers: implications for the development of proximal humeral epiphysiolysis and humeral retrotorsion. *Am J Sports Med* 2005;**33**:1716–22.
25. **Meister K**, Day T, Horodyski M, *et al*. Rotational motion changes in the glenohumeral joint of the adolescent/Little League baseball player. *Am J Sports Med* 2005;**33**:693–8.
26. **Crockett HC**, Gross LB, Wilk KE, *et al*. Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. *Am J Sports Med* 2002;**30**:20–6.
27. **Pieper HG**. Humeral torsion in the throwing arm of handball players. *Am J Sports Med* 1998;**26**:247–53.
28. **Olsen SJ** II, Fleisig GS, Dun S, *et al*. Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *Am J Sports Med* 2006;**34**:905–12.
29. **Lyman S**, Fleisig GS, Andrews JR, *et al*. Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *Am J Sports Med* 2002;**30**:463–8.
30. **Nissen CW**, Westwell M, Ounpuu S, *et al*. A biomechanical comparison of the fastball and curveball in adolescent baseball pitchers. *Am J Sports Med* 2009;**37**:1492–8.
31. **Davis JT**, Limpisvasti O, Fluhme D, *et al*. The effect of pitching biomechanics on the upper extremity in youth and adolescent baseball pitchers. *Am J Sports Med* 2009;**37**:1484–91.
32. **Gill TJT**, Micheli LJ. The immature athlete. Common injuries and overuse syndromes of the elbow and wrist. *Clin Sports Med* 1996;**15**:401–23.
33. **Carson WG** Jr, Gasser SI. Little Leaguer's shoulder. A report of 23 cases. *Am J Sports Med* 1998;**26**:575–80.
34. **Burkhart SS**, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy and biomechanics. *Arthroscopy* 2003;**19**:404–20.
35. **Tarkin IS**, Morganti CM, Zillmer DA, *et al*. Rotator cuff tears in adolescent athletes. *Am J Sports Med* 2005;**33**:596–601.
36. **Andrews JR**, Fleisig GS. How many pitches shoulder I allow my child to throw? USA Baseball Newsletter, 1996.