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Biomechanics/Pathophysiology/Classification of Injury
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Injuries to the Shoulder in the Throwing Athlete

Part One: Biomechanics/Pathophysiology/Classification of Injury

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ABSTRACT

Over the last decade, significant advances have been made in the study and understanding of shoulder mechanics. Much of this may be attributed to the use of more sophisticated technology to improve our ability to assess the shoulder in real-time athletics. As a consequence of these advances, our understanding of the pathophysiology of injury has also increased. Our manual examination skills have improved and our noninvasive diagnostic techniques have advanced greatly. New insight into forces at play during actions as complex as the throwing motion has allowed us to develop better protocols for the prevention and treatment of the most common injuries. Additionally, paralleling improvements in the understanding of shoulder kinematics and the pathophysiology of injury, advances in surgical techniques, particularly arthroscopy, have aided in the diagnosis of and the development of less invasive surgical treatments for injuries that do not respond to nonoperative measures. Undoubtedly, an up-to-date understanding of the developments in shoulder biomechanics, pathophysiology of injury, diagnostic techniques, and surgical management is necessary for the clinician who wishes to continue to apply proper skills in the sports medicine setting.

BIOMECHANICS

Static limits of glenohumeral motion for all activities are imposed by the geometry of the articular components of the cavity as well as the soft tissue envelope. The extremes of motion achieved during the normal throwing motion put all of these structures at risk. Additionally, the speed with which the action occurs results in the extreme use of the dynamic stabilizing structures, increasing their vulnerability to injury.

Throwing Motion

The overhand throwing motion occurs in six phases. De- lineation between the phases is determined by changes in forces and muscle firing that occur during the cycle (Fig. 1). Although many other movements have been studied (such as the volleyball spike, golf swing, and tennis serve), there are enough parallels between movements that the overhand throw serves as the most commonly used model.1,62,66 From a mechanical perspective, the goal of the motion is to sequentially develop a package of potential energy that is then converted to kinetic energy that can be imparted to the ball in an efficient and fluid manner.

Phase I, the wind-up, is the readying phase during which the body’s overall center of gravity is raised with minimal stress imparted to the shoulder. At the end of this phase, the shoulder is in minimal internal rotation and slight abduction, with minimal muscular activity.

Phase II, early cocking, a minimal load phase, moves the shoulder into 90° of abduction and 15° of horizontal abduction (with the elbow posterior to the plane of the torso). The initiation of this phase is marked by early activation of the deltoid muscle and late activation of the supraspinatus, infraspinatus, and teres minor muscles.
Phase III, late cocking, begins with the planting of the striding leg and ends with the shoulder in a position of maximum external rotation, 170° to 180°. The scapula retracts to facilitate this position and form a stable base for the humeral head, from which the next phase can begin. Shoulder abduction is maintained at 90° to 100°, and horizontal positioning moves to 15° of adduction (with the elbow anterior to the plane of the torso). The combination of abduction and external rotation results in obligatory posterior translation of the humeral head on the glenoid. Deltoïd muscle firing decreases, and supraspinatus, infraspinatus, and teres minor muscle activity reaches its peak in the midportion of this phase. In the terminal portion, subscapularis muscle firing is initiated as the torso begins to open up as it rotates forward (Fig. 2). Biceps muscle activity is moderate and increased firing of the pectoralis major, latissimus dorsi, and serratus anterior muscles mark the end of the phase, creating a maximum horizontal adduction of 100 N·m and internal rotation torque of 70 N·m (Fig. 3). Rotation of the torso results in a shear force across the anterior shoulder of 400 N, with rotator cuff muscles firing generating a compressive force of 650 N.

Phase IV, acceleration, rotates the shoulder to the ball release point of 90° rotation, maintaining shoulder abduction. The scapula begins to protract, maintaining a stable base for the humeral head as the body moves forward, allowing for the conversion of muscle function from eccentric to concentric anteriorly and from concentric to eccentric posteriorly. Quite remarkably, shoulder loads are minimal as the arm rotates internally at velocities greater than 7000 deg/sec. The triceps muscle has marked activity early and the pectoralis major, latissimus dorsi, and serratus anterior muscles have marked activity late. With horizontal abduction occurring to the neutral position, minimal posterior shear stresses (50 N) extend across the back of the shoulder. The humeral head re-centers as the capsule unwinds.

Phase V, deceleration, which is recognized as the most violent phase of the throwing cycle, is responsible for the dissipation of the remaining energy that is not imparted to the ball. Deceleration is an essential reversal of the first three phases of the throwing cycle. This phase begins at ball release and ends with the cessation of humeral rotation to 0°. Shoulder abduction is again maintained at 100° and horizontal adduction increases to 35°. A violent contraction of all muscle groups occurs, with eccentric contraction necessary to slow down arm rotation. Joint loads are at their greatest in this phase, with recorded posterior shear forces of 400 N, inferior shear forces of greater than 300 N, and compressive forces of greater than 1000 N. Adduction torque of greater than 80 N·m and horizontal abduction torque of nearly 100 N·m are generated.

Finally, phase VI, the follow-through, is the rebalancing phase where the body moves forward with the arm until motion stops. Shoulder rotation drops to 30° as horizontal adduction increases to 60°, and abduction is maintained at a constant 100°. Muscle firing returns to resting levels, and joint loads decrease, but compressive forces can still
be calculated at approximately 400 N, inferior shear at approximately 200 N, and anterior shear at approximately 75 N.12,16

The entire throwing motion takes less than 2 seconds. The wind-up and cocking phases require approximately 1.5 seconds. The acceleration phase takes approximately 0.05 seconds, and the deceleration and follow-through phases take approximately 0.35 seconds.12,16,19,60

Types of Pitches

The kinematics of the fastball, change-up, curve ball, and slider pitches have been evaluated and compared by Escamilla et al.,14 who described the measurement of 26 different kinematic parameters of late cocking, acceleration, and deceleration and compared them between the four pitches. Significant differences were found in 60% of these parameters; however, only rotational angular velocity differed by more than 1%. The greatest differences in peak shoulder angular velocities occurred between the change-up and fastball/slider pitches (6700 versus 7600 to 7900 deg/sec).

Baseball Versus Football

Although the phases are similar in the throwing motions of baseball and football, the increased weight of the football appears to affect shoulder position and stresses in all phases. Quarterbacks rotate their shoulders sooner and achieve maximum external rotation earlier in the throwing cycle than do pitchers, probably allowing more time for acceleration during internal rotation. However, even with the increased time afforded internal rotation, internal rotation velocities are significantly less when throwing a football, 7600 versus 5000 deg/sec.

A second mechanical adjustment produced by the heavier football is leading with the elbow. Increased shoulder horizontal adduction coupled with increased elbow flexion is needed in the late cocking phase to decrease the impact of the heavier football by shortening the lever arm. This lessens potential loads on the shoulder. The more erect position of the quarterback when throwing the ball and the decreased contribution from the trunk and legs result in decreased arm velocity. Therefore, a complete follow-through, seen in the baseball pitch as the torso falls forward, is not observed in the quarterback throw. The erect finish of the quarterback keeps him out of a more vulnerable position, that is, bent over and unable to escape impact from an oncoming rush. The overall lower torques and forces generated on the throwing shoulder of the football player may also account for the lower incidence of shoulder injuries in this sport (Fig. 4).20

Softball Pitch

Little work has been done to date comparing the windmill softball pitch to the overhand throwing motion in athlet-
ies, in spite of the fact that injury to the pitching shoulder can account for significant time-loss injuries during the course of a season.47 One study has been performed, however, evaluating muscle-firing patterns of the major muscle groups. Significant similarities between the overhead and underhand throw were found.48

In contrast to the overhand throw, the windmill pitch is performed with the humerus primarily in the plane of the body, which eliminates significant contribution of the posterior cuff musculature in both the acceleration and deceleration phases (Figs. 5 and 6). Additionally, the muscle action following ball release is significantly lessened in deceleration secondary to the arm striking the lateral thigh in follow-through.48 Thus, the incidence of injury from this normally burdensome phase should be considerably less than in the overhand motion.

Similarities exist between the role of the subscapularis and pectoralis major muscles as they provide stabilization against anterior forces across the shoulder, and the role of the serratus anterior muscle as a scapulohumeral stabilizer maintaining the center position of the humeral head on the glenoid. Addition of the arm across the body by the pectoralis major muscle contributes to the power of the pitch.48

Strength Profiles

Isokinetic testing of shoulder strength has been performed on athletes at the high school, collegiate, and professional levels of throwing.8, 13, 29, 55, 70, 79, 80 Strength profiles, with some minor variations, are consistent among studies comparing shoulders on the collegiate and professional levels. Only a single study found differences between the dominant and nondominant shoulders with respect to overall concentric strength in internal rotation or abduction/adduction.70 Weakening of the external rotators can exist in the dominant relative to the nondominant arm, altering strength ratios. Testing in the functional position, 90° of abduction, appears to be a more sensitive way of manifesting differences.8, 29, 55, 79, 80 The exact cause of the weakening of the dominant external rotators cannot be fully explained at this time. Mean peak torque ratios of external-to-internal rotation concentric strength have been measured as 65% at 180 deg/sec and 61% at 300 deg/sec.

In testing concentric adduction and abduction, a significant difference exists between adduction strength characteristics in the throwing versus nonthrowing shoulder. Adduction strength is significantly greater in the dominant shoulder. For test speeds of 180 and 300 deg/sec, strength ratios of adduction to abduction are measured as 82.5% and 93.8%, respectively, in the dominant shoulder, versus 66% and 70%, respectively, in the nondominant shoulder. The need for significant strength in the adductor muscles probably best explains asymmetries found in testing, specifically for the latissimus dorsi and pectoralis major muscles in the acceleration and deceleration phases of throwing.

Isolated isokinetic eccentric muscle performance has also been measured. In separate populations of collegiate and professional throwers, no differences existed between the dominant and nondominant extremities. Eccentric strength was significantly greater than concentric strength for all muscle groups. For both internal and external rotation, eccentric strength differences were greater than concentric strength by 10% to 15%.55, 70

Some differences in younger throwers seem to exist. In one study of the isokinetic strength characteristics in high school pitchers, significant differences in internal rotation strength were shown between the dominant and nondominant extremities. Testing both extremities at the neutral and 90° abducted position, peak torque and total work values for the internal rotators on the throwing side were significantly higher than for those on the nonthrowing side in all tests.29

Adaptive Changes

Adaptive differences in the dominant shoulder and arm of the pitcher have been recognized for a long time.6, 43 Hypertrophy is perhaps the most striking difference and involves the entire shoulder girdle, including the anterior and posterior chest wall muscles. Isolated wasting of the infraspinatus muscle within the fossa is also common. Less overt differences in shoulder range of motion and capsular laxity have also been well documented.7, 8, 42, 43

A marked loss of internal rotation is often observed in the dominant or pitching shoulder. Additionally, a marked increase in external rotation over the nondominant extremity can range from 9° to 16° in both position players and pitchers. However, the gain in external rotation of the

Figure 5. The six phases of the windmill softball pitch. (Reprinted from Maffet et al.48)
pitching shoulder does not normally make up for the loss of internal rotation. Therefore, there is an overall loss of shoulder motion as the career of the pitcher extends.7,8 Such changes have also been observed over the careers of tournament-level tennis players.42

Differences in shoulder laxity as determined by an increased prevalence in the sulcus sign have been recorded. The presence of the sulcus sign has been shown to be more prevalent in pitchers than in position players.56 Increases in anterior glenohumeral translation with the shoulder in an abducted and externally rotated position have been shown radiographically in athletes with symptomatic anterior instability.30

INJURY TO THE SHOULDER

Although overuse of the throwing shoulder can contribute significantly to injury, many difficulties begin with improper mechanics and poor conditioning. Common problems in pitching mechanics that can lead to injury begin with the foot plant. Hyperextension of the knee while planting the striding leg and landing on the heel cause a sudden deceleration of the body, which results in undue counterforce on the throwing arm. Such a maneuver is often seen in pitchers who are “overthrowing” and trying to get more velocity on their fastballs.68

The planted foot should always point toward home plate. Placing the striding foot outside the target (toward the first-base side for a right-handed pitcher) and wide to the torso results in “opening up too soon.” In this instance, pelvic rotation occurs too early, creating increased stress across the anterior shoulder and elbow. Planting the foot toward the third-base side of home plate slows down rotation of the torso, taking from the body’s momentum and forcing the throw to be delivered entirely by the arm.

The throwing motion should be a smooth acceleration and deceleration of the center of gravity toward the target. This fluid motion should be maintained regardless of the type and velocity of pitch being thrown.21,68

Classification of Injury

Injury from throwing can occur to any of a number of structures contributing to the dynamic or static restraint of the shoulder. Although injuries can be classified by anatomic part, a greater understanding of pathophysiology and more appropriate algorithms for treatment can be developed by classifying injury by pathomechanics. Isolated injury to the rotator cuff, labrum, and capsule can occur, but far more frequently, injury to one structure is secondary to the breakdown of another. Kvitne and Jobe44 have developed a classification system related to instability that attempts to categorize injuries into four groups. However, recognition of additional factors contributing to the pathomechanics of injury has led this author to add a category (called posterosuperior glenoid impingement) and expand on the initial classification system created by Kvitne and Jobe (Table 1).

I. Primary Disease (Table 1). Primary disease refers to injury that occurs in the throwing shoulder that can be attributed to the normal, but excessive, forces and extreme motions seen in all throwers. The stresses across the joint during the throwing motion in the stable shoulder are great enough to result in damage to the static and dynamic restraints even without significant underlying glenohumeral instability. In some athletes with articular or periarticular injury, assessment of glenohumeral laxity may reveal only minimal-to-no asymmetric laxity.36,37,52 In such instances, the disease may be considered primary, and not secondarily related to a breakdown of the static capsular restraints.

Rotator Cuff/Biceps Superolabral Complex. As the supraspinatus, infraspinatus, and teres minor muscles fire in the late cocking phase of a throw, rotator cuff muscle function becomes significant as the superior and posterior cuff muscles move the shoulder to the point of maximum external rotation. Those same muscles fire violently during the deceleration phase, as significant posterior shear and compressive loads are recorded across the joint.

Tendons are maintained by the tenocyte production of collagen. The tenocyte must be able to increase collagen and matrix production in response to increased loading. Additionally, an adequate blood supply must exist to maintain viability of the tenocytes. The area of insertion of the supraspinatus muscle has been shown to be a watershed area of diminished blood flow that is particularly susceptible to repetitive overload stresses.63 The normal processes of aging have also been shown to be a major contributing factor to the failure of the rotator cuff.69,75

The repetitive stresses of throwing may speed up normal degeneration that can occur over time.69,75 Therefore, repetitive stressful loading of the rotator cuff as the cuff muscles attempt to resist distraction, horizontal adduction, and internal rotation of the shoulder during arm deceleration can result secondary to fatigue in an acute inflammatory response in the early stages and in tendon failure in the late stages.52

During the late cocking phase, biceps muscle firing is only moderate. However, during deceleration, biceps muscle contraction is particularly strong (although only to 44% of maximum muscle contraction) as it contracts to both decelerate elbow extension and act with the rotator cuff to resist glenohumeral distraction.11,16,17 A study

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TABLE 1

<table>
<thead>
<tr>
<th>Classification of Shoulder Instability36,37</th>
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<tbody>
<tr>
<td>I. Primary Disease (overuse syndromes)</td>
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<tr>
<td>Primary tendinitis (rotator cuff/biceps)</td>
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<tr>
<td>Tensile rotator cuff failure</td>
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<tr>
<td>SLAP lesions</td>
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<tr>
<td>Subacromial impingement</td>
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<td>Bennett’s lesion</td>
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<td>II. Primary instability</td>
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<td>A. Secondary to repetitive microtrauma</td>
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<tr>
<td>Secondary impingement</td>
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<td>Labral tears</td>
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<td>Fraying</td>
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<td>SLAP lesions</td>
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<td>B. Secondary to generalized ligamentous laxity</td>
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<td>III. Acute traumatic instability</td>
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<tr>
<td>IV. Posterosuperior glenoid impingement</td>
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that evaluated the role of the biceps muscle and superior labrum in anterior instability of the shoulder suggests that the biceps muscle is essential to limiting torsional forces to the shoulder in the abducted, externally rotated position.65

In the position of extreme external rotation, the biceps muscle may have two functions. It is primarily an internal rotator to the humerus. Its secondary function is to resist distraction and compress the humeral head against the glenoid.65 Biomechanical studies have also shown that anterosuperior and posterosuperior labral strain are greatest in shoulder abduction.65 Biceps tendon strain is greatest in shoulder adduction.26

Biceps muscle load may increase as a result of excessive throwing and poor mechanics. With proper pitching mechanics, maximum elbow flexion torque occurs before maximum shoulder compressive force.12,16 With improper mechanics, these two loads may occur closer together in time, requiring a greater maximum force by the biceps muscles.17 Loss of the biceps muscle anchor with complete avulsion of the superolabral complex with the arm in the cocked position may reduce torsional rigidity as much as 38%. As a result, strain in the inferior glenohumeral complex may increase as much as 100%. Therefore, initial failure of the biceps-superolabral complex may contribute to late failure of the anterior glenohumeral ligaments.

Andrews et al.,4 in a series of 73 baseball pitchers undergoing arthroscopic examination, noted significant tearing of the superolabral complex in all 73 players, with most injury occurring in the anterosuperior portion of the complex. The force of pull of the biceps muscle was observed in the area of abnormalities by enervation of the complex. The force of pull of the biceps muscle was observed in the area of abnormalities by enervation of the biceps and observation during arthroscopic examination. Injury may therefore manifest as acute or chronic tendinitis.4,5,9,24 However, true avulsions of the biceps tendon (type II superior labrum, anterior to posterior [SLAP] lesions) are somewhat uncommon in the throwing athlete.72,74 These lesions are more likely to occur from direct compression of the greater tuberosity on the superior and posterior labrum in the abducted shoulder.72

Andrews et al.4 have also introduced the concept of the “grinding factor” as a potential cause of labral damage in the stable throwing shoulder. This factor results from translation of the humeral head during arm acceleration and deceleration. Humeral head displacement combined with compression and internal rotation during deceleration can cause the humeral head to grind on the labrum.51 Thus, tears at the base of the biceps tendon as well as at the anterosuperior portion of the labrum are commonly seen.4,24,49

Subacromial impingement, as described by Neer,57 may also be a factor contributing to primary disease of the rotator cuff and biceps tendon. The shoulder is repeatedly positioned at 100° of abduction and, with every throw, moves from external horizontal abduction to a position of horizontal adduction and internal rotation. During the arm deceleration phase, a large inferior force and adduction torque is produced.12,16 With weakness in the rotator cuff muscles, fatigue, or improper mechanics, an inability to generate needed forces can lead to superior migration of the humeral head and subacromial impingement. Additionally, loss of internal rotation that can occur over an athlete’s career, partly from contracture of the posterior capsule, has been shown to result in anterior and superior migration of the humeral head.26 Superior migration of the humerus causes impingement of the greater tuberosity, rotator cuff muscles, or biceps muscle against the inferior surface of the acromion or coracoacromial ligament.17

Bennett’s Lesion. In 1941, Bennett6 was the first to describe the presence of a bony exostosis on the posteroinferior border of the glenoid fossa (Fig. 7). He observed that this location corresponds to the attachment of the posterior capsule, as well as the area of insertion of the long head of the triceps muscle. Bennett thought that this was a symptomatic lesion that caused irritation of the capsule and the synovial membrane and, at times, irritation of the axillary nerve, referring pain to the deltoid muscle. Lombardo et al.46 also described symptomatic posterior bone formation within the capsule of four throwers. Additional damage to the posterior labrum and lesions of the humeral head were treated successfully with debridement.

Most recently, it has been accepted that the exostosis probably occurs from traction of the posterior band of the inferior glenohumeral ligament during deceleration.53 In the symptomatic shoulder, the exostosis is often associated with tearing of the posterior labrum and posterior rotator cuff.15,52 However, a large enough isolated lesion may be a source of posterior pain and, possibly, pain referred to the lateral deltoid muscle secondary to entrapment of the axillary nerve.65,63,59

II. Primary Instability (Table 1). a. Secondary to Microtrauma. The late cocking and early acceleration phases of the throwing cycle, in particular, place significant shear across the anterior aspect of the shoulder during normal throwing. Rotation of the torso after foot plant has been previously noted to generate an anterior shear estimated at 400 N.12 Over time, secondary to poor mechanics (“opening up” in late cocking), overthrowing, or weakness,
the anterior capsule sees increasing loads unshielded by equal contributions of the surrounding musculature. The anterior capsule then fatigues and fails, resulting in increased anterior laxity of the glenohumeral joint.

Failure of the anterior capsule leads to increased anterior translation in the most stressful phases of the throwing cycle. Manifestations of this increased laxity include secondary rotator cuff tendinitis or subacromial impingement, anterior labral fraying from increased translation in deceleration, SLAP lesions, and posterior glenohumeral impingement. Distinguishing lesions that occur secondary to instability from those that result from primary forces on the shoulder during throwing is paramount in the ultimate treatment of this group, as correction of the observed lesion without correction of the instability will eventually lead to recurrence.3,9,49,58,67

The relocation test developed by Jobe and colleagues36,37 may assist in distinguishing structures that fail from primary overload from failures secondary to acquired anterior instability. For this test, the patient is placed in the supine position on the examining table. The arm is placed in 90° of abduction and rotated into a position of maximum external rotation. Anterior or superior shoulder pain, or apprehension elicited with this maneuver that is abated by a posteriorly directed force on the anterior shoulder, provides evidence of occult instability. Apprehension without pain suggests isolated occult instability. Apprehension coupled with pain may represent occult instability with secondary rotator cuff disease (Fig. 8). Additionally, significant asymmetric glenohumeral laxity elicited by standard techniques (for example, anterior/posterior drawer tests) may also provide evidence of occult instability.22

II. Primary Instability (Table 1). b. Secondary to Generalized Ligamentous Laxity. Persons with this type of instability exhibit signs of generalized ligamentous laxity. These athletes exhibit bilateral, symmetric increases in shoulder laxity, as opposed to the athletes in group IIa with asymmetric shoulder laxity. For these patients, the relocation test is often positive and glenohumeral translation is globally excessive (that is, 2+ or greater). These patients often exhibit hyperextension at the elbow, knee, and metacarpophalangeal joints, and have the ability to place the abducted thumb against the forearm.36,37,78 The microtrauma of throwing, coupled with a baseline level of increased symmetric laxity, puts this athlete at risk for developing damage to the intra- and periarticular structures of the shoulder. As a result of their increased baseline level of laxity, many of these athletes will throw with the most velocity and ball movement but will have the greatest risk of long-term injury.

Arthroscopic examination of the glenohumeral joint of athletes with this type of instability reveals a hypoplastic glenoid labrum and an increased joint volume. Abnormalities of the labral complex and rotator cuff are often seen.5,36

III. Acute Traumatic Instability (Table 1). Although common in athletics in general, this cause of instability is seen least in the overhead throwing athlete. A specific acute traumatic event leading to a unidirectional pattern of instability is characteristic. Complaints of pain while throwing may be present, but instability is often the primary complaint. Significantly positive apprehension and relocation tests and asymmetric, unidirectional glenohumeral laxity are detected.36,50,52 An athlete who attempts to continue to throw after this event and does not develop overt primary instability may often manifest difficulties with secondary damage to the structures previously described, the rotator cuff and the superior and posterior labral complexes.

IV. Posterosuperior Glenohumeral Impingement (Table 1). The concept of impingement occurring in the shoulder at a spot other than in the subacromial space is relatively new. Although in a historical review of the literature there is

Figure 8. Relocation test developed by Jobe and colleagues.36,37 A, symptoms of pain and impingement are generated in abduction and maximum external rotation; B, symptoms are eliminated with a posteriorly directed force on the humeral head.
suggest of such a mechanism of injury to the rotator cuff and glenoid, the clinical significance of internal impingement was not uncovered until Walch et al. published their article in the early part of this decade. Since that time, a number of other authors have presented further evidence in support of this mechanism of damage to the rotator cuff and glenoid in athletes who use the overhead throwing motion.

Limits of capsular restraint and contact of the greater tuberosity on the glenoid impose constraints on glenohumeral joint motion. Contact of the greater tuberosity on the glenoid is most critical in varying positions of elevation and external rotation. Forceful contact of the tuberosity against the superior glenoid has long been believed to be a mechanism of fracture of the greater tuberosity. In overhead throwing sports, repeated extreme movements of glenohumeral abduction and external rotation result in contact of the superior and posterior glenoid rim with the supraspinatus muscles and posterior humeral head (Fig. 9). The lower loads of throwing do not result in fracture but can produce undersurface tearing of the rotator cuff, tearing of the posterior or superior labrum, and changes on the posterior humeral head (expanded bare area and cyst formation).

In a normal stable shoulder, contact of the tuberosity with the glenoid is possible. There may be factors, however, that contribute to a more pathologically significant contact in the athlete in overhead throwing sports. Increased impingement may result from increased anterior capsular laxity. A loss of normal posterior translation in the late cocking and early acceleration phases of throwing may result in impingement of the undersurface of the rotator cuff rather than the posterior humeral head. Repetition of this contact may be responsible for tearing of the undersurface of the rotator cuff and posterosuperior glenoid labrum. Increased capsular laxity, resulting in increased anterior translation as well as increased external rotation (commonly seen in throwers), can further increase the degree of internal contact. As the arm horizontally adducts and internally rotates during acceleration and deceleration, further grinding and contact of the greater tuberosity, as previously described, may be responsible for more significant tears of the superior labral complex.

Some authors have also suggested that differences in humeral version may be responsible for more refractory cases of internal impingement. Decreased humeral retroversion in the dominant shoulder in maximum external rotation may result in increased contact of the posterior humeral structures with the glenoid (Fig. 10).

The thrower with internal impingement will most often complain of pain in the posterior aspect of the shoulder in the late cocking and early acceleration phases of throwing. An inability to fully rotate the shoulder secondary to posterior pain will cause a loss of velocity. An early ball release results in loss of control.

The posterior impingement sign can confirm a diagnosis of tears to the posterior labrum or rotator cuff, or both. In this test, the patient is positioned supine with the shoulder placed into a position of 90° of abduction and maximum external rotation. Re-creation of the throwing symptoms with the arm in this position—complaints of pain deep within the posterior aspect of the shoulder—is diagnostic (Fig. 11). With the arm horizontally adducted, the same pain can be elicited by deep palpation of the posterior cuff and capsule (Fig. 12). Applying a posteriorly directed force to the humeral head while in a position of 90° of abduction and maximum external rotation, as in the relocation test, may also be diagnostic if the posterior pain is reduced or eliminated.

Figure 9. Impingement of the undersurface of the rotator cuff against the glenoid labrum at maximum shoulder external rotation.

Figure 10. A, the effect of decreased humeral retroversion on internal impingement; B, increasing retroversion decreases internal impingement. (Reprinted from Riand et al.)
SCAPULOTHORACIC JOINT

The scapula, although often neglected in the evaluation of the symptomatic shoulder, is of critical importance in maintaining a foundation for normal physiology and biomechanics. Kibler outlines five essential roles for the scapula in athletic shoulder function. The scapula provides for a stable base in the glenohumeral articulation, retraction and protraction of the shoulder complex along the scapular wall, elevation of the acromion, a base for muscle attachment, and a link to the transfer of forces from the trunk to the arm in the normal throwing motion.

The periscapular musculature works in tandem pairs to allow for stabilization and, when necessary, elevation of the acromion. The appropriate force couples for scapular stabilization include the upper and lower portions of the trapezius muscle and rhomboid muscles, paired with the serratus anterior muscle. The appropriate force couples for acromial elevation are the lower trapezius and serratus muscles paired with the upper trapezius and rhomboid muscles. Balanced function of the muscle groups is essential to the efficient function during the kinetic chain of events.

Injury/Dysfunction

Scapular dysfunction occurs from abnormal function and imbalance in the workings of the periscapular musculature. The most common causes of dysfunction are direct trauma to the scapular musculature and indirect injury from repetitive microtrauma (as in the throwing shoulder or muscle inhibition from painful conditions of the shoulder). The serratus anterior and lower trapezius muscles are the most sensitive to this inhibitory effect. Thus, their dysfunction becomes evident early in abnormalities of the glenohumeral joint.

Less commonly, nerve injury, specifically to the long thoracic nerve or spinal accessory nerve, can result in scapular dysfunction. Loss of glenohumeral motion can also result in scapular dysfunction. Particularly in the throwing athlete, tightness in the posterior capsule and musculature leads to increased protraction of the scapula in cocking and follow-through phases. The increased protraction results in more anterior and inferior movement of the scapula, closing down the subacromial arch, which leads to decreased clearance of the rotator cuff and increased impingement.

Lack of full scapular retraction causes loss of a stable cocking point, dissipating the flow of energy from the torso and trunk to the arm. According to Kibler, a 20% decrease in energy delivered from the trunk to the arm necessitates a 34% increase in rotational velocity at the shoulder to deliver the same amount of resultant force. Loss of coordinated retraction/protraction also results in relative glenoid anteversion, which leads to the loss of the normal bony buttress to resist anterior translation of the humeral head. With relative loss of this bony buttress, increased shear is felt across the anterior soft tissue structures and leads to injury.

Lack of appropriate acromial elevation in the cocking and follow-through phases can result in impingement problems. Inhibition or fatigue of the lower trapezius and serratus anterior muscles can lead to relative closure of the coracoacromial arch. Relative loss of the arch space can result in primary impingement or contribute to the problems of secondary impingement in cases of concomitant instability.

The Skeletally Immature Thrower

Biomechanics

Interestingly, although little data are currently available comparing adult throwing patterns with those of young throwers, the data that do exist show remarkably little difference in the kinetic and kinematic parameters of the two. A study comparing parameters in four age groups found that only force production varied significantly. These authors found no differences in temporal parameters.
ters, meaning that maximum angular velocities and rotations occurred at the same time (as a percentage of time from front-foot contact to ball release) in all age groups. Shoulder position in the horizontal and coronal planes, as well as maximum external rotation achieved, were similar in all groups. However, shoulder internal rotation torque and anterior shear force in adolescent throwers were less in cocking. In deceleration, posterior shear and compressive forces were less. Shoulder internal rotational velocities were reduced secondary to decreased muscle mass. Additionally, as a consequence of decreased angular velocity and shorter lever arms, velocity of the ball at release was also less. However, no significant mechanical differences were found in the healthy young thrower that would limit pitching in the young adult population. Thus, whatever the age of the athlete, the goal of coaching should be to correct abnormal movements and produce normally accepted mechanics of the shoulder.

The study of Little League players by Albright et al. tended to support the observation that injury occurs secondary to poor mechanics. They found that the incidence of symptoms in the Little League pitcher correlated best with the form of pitching rather than the pitcher’s age. Slager also suggested that the initial development of pitchers should emphasize skills and control, and later, velocity.

Injury

As evidenced in the data previously provided, the shoulder in young throwers is subject to most of the same stresses as in the adult thrower, but at a reduced magnitude. Therefore, the joint is subject to many of the same problems, with certain exceptions. Elbow problems are far more common than shoulder problems in young throwers. Shoulder problems do not tend to develop until the mid-to-late teens. However, many of the same overuse conditions seen in the adult population may be seen in the preteen and young adolescent: rotator cuff tendinitis, biceps tendinitis, and capsular strains. Acromioclavicular joint problems are extremely uncommon in young throwers, and there has been only one case report of coracoid avulsion through the epiphysis in a young thrower.

SUMMARY

The throwing motion involves a series of phases that stress to their limits the dynamic and static restraints of the glenohumeral and scapulothoracic joints. Therefore, maintaining a balance of proper biomechanical forces is essential to avoiding injury. A basic understanding of the phases and the forces at work during each portion of the throwing cycle allows for an improved understanding of the mechanisms that result in the common profiles of injury. Few biomechanical differences exist between the different types of pitches thrown. Significant differences do exist between the overhand baseball, underhand softball, and football throwing mechanics. Increases in adduction strength and possible decreases in strength of external rotation may exist in the dominant arm of the thrower. These differences in strength characterize the alteration in strength ratios between the dominant and nondominant arms. Surprisingly, no significant differences were found between the throwing motions of the young and the adult thrower. Similar mechanical breakdowns in each can lead to the development of injury.

The distinction between laxity and instability in the throwing shoulder is not always apparent. Increased external rotation and glenohumeral translation are consistently found in the most effective of overhand throwing athletes. Classification of injury as primary disease, primary instability, acute traumatic instability, or posterior impingement can assist in the development of an algorithm for treatment. Clinical assessment of laxity, the relocation test, and the posterior impingement sign are clinical tools useful in making these distinctions. However, the cause of disease is often multifactorial, and a distinct categorization of each case may not be possible. Therefore, how much motion is too much and how much laxity is too much are not always easy to assess. Undoubtedly, an improved understanding of the pathophysiology of injury will aid the clinician in the evaluation and development of a proper treatment plan for the injured athlete.

REFERENCES
