The baseball pitch places tremendous stress upon the upper extremity. In particular, the large forces and torques underlying the overhand throw transfer significant stress to the shoulder. These stresses lead to microtrauma in the soft tissues surrounding the shoulder and, with repetitive throwing, can result in overuse injuries. A delicate balance exists between mobility and stability at the shoulder, and a fine line separates optimal athletic performance and unwanted injury.

Atwater’s study of overarm throwing used motion analysis to investigate the kinematics of throwing and mechanisms of throwing injuries. High-speed cinematography and video digitizing provide a three-dimensional analysis of the pitching motion, allowing for further investigation of the kinetics of throwing. Electromyographic (EMG) studies have revealed the muscle activation patterns involved in the pitching motion: precise coordination of the upper limb musculature is necessary to generate the requisite forces while still stabilizing the shoulder to prevent injury.

To facilitate its interpretation, the pitching motion is divided into six phases: windup, early cocking (stride), late cocking, acceleration, deceleration, and follow-through (Fig. 1). As an overview of the general mechanism, the pitching motion can be described in terms of an anatomical link system. Beginning with the front foot, proceeding up through the hips and trunk, and ultimately leading to the throwing arm, the complex act of pitching involves the sequential activation of the entire body. As a segment of the body (e.g., the trunk) undergoes acceleration, the succeeding segment (e.g., the arm) is physically left behind. When the trunk begins to decelerate, the arm acquires the velocity of the trunk. Then, as the forces that act on the arm are applied, the arm accelerates to an even greater velocity. Ultimately, the motion acquired by the throwing arm through this mechanism generates the torque that applies the force to the ball.

A variety of different shoulder injuries can occur from the chronic stresses of pitching. This paper describes the shoulder biomechanics and injuries that occur during the late cocking and acceleration phases of the baseball pitch. Anterior instability and bicipital tendinitis, common causes of shoulder pain in the baseball pitcher, result from the extremes of motion that occur during arm cocking. Subacromial impingement can occur in older pitchers as they internally rotate and horizontally adduct the abducted arm during acceleration. The second part of this article describes the shoulder biomechanics and injuries that occur during the deceleration phase of the pitch, including posterior instability, isolated rotator cuff tears, the SLAP lesion, and the Bennett lesion, a lesion peculiar to baseball players.

Despite varying etiologies, shoulder injuries in baseball pitchers usually present with pain. A thorough understanding of the biomechanical sources for injury has enabled the development of effective treatment and rehabilitation regimens, often allowing baseball pitchers to return to their sport at their previous levels of competition.

Windup and Early Cocking

Few injuries occur during the early phases of the pitching motion. However, an adequate elaboration of the biomechanics of the windup and early cocking is necessary to understand how the large forces and velocities are generated with pinpoint timing during the later phases of the baseball pitch. While the mechanics of the windup vary
widely from pitcher to pitcher, the vital role of the windup in the pitching motion is constant. The windup begins when the pitcher initiates his motion and ends when he removes the ball from his glove (Fig. 1A and B). An essential component of the windup is the “push off,” in which the stride leg (the leg contralateral to the pitching arm) pushes off from behind the pitcher, shifting the body weight from the stride foot to the pivot foot (the foot ipsilateral to the pitching arm). The push off moves the center of gravity of the body in a forward direction so that it will continue to be driven forward toward the plate instead of upward when the pivot leg extends during the subsequent early cocking phase.2 As the stride leg pushes off, three movements occur simultaneously. With the ball concealed from the batter in the glove, both arms flex forward, the body rotates 90° so that the gloved side of the body faces the batter, and the stride leg is elevated and flexed in front of the body. This places the pitcher in a position so that all parts of his body may contribute to the propulsion of the ball.3 It is important to appreciate the contribution of the lower body and trunk to the velocity of the throw. Toyoshima and colleagues10 reported that “approximately 50 percent of the velocity of the overhand throw resulted from the step and body rotation, and the remainder came from the shoulder, elbow, wrist, and finger action.” Coordination in the pivoting motion of the lower extremities is essential to optimal delivery of the ball.11 After the windup, the knee of the pivot leg is flexed, lowering the center of gravity, and the stride leg extends and moves toward the batter while the ball is simultaneously removed from the glove. The trunk is kept as far back as possible to maximize its potential for rotation (which occurs momentarily) and therefore its contribution to the velocity of the pitch.3 As the stride leg continues to extend toward the batter, the knee and hip of the pivot leg extend as well, propelling the body forward into the stride (Fig. 1C). At the same time, the hips begin to rotate forward, followed by forward rotation of the trunk. As the stride develops, the throwing arm follows a down-and-up-motion in rhythm with the body as the throwing shoulder is brought into a pattern of abduction, extension, and internal rotation. The down-and-up-motion of the throwing arm serves to ensure proper synchrony between the throwing arm and the body.3 With proper coordination, the throwing arm will be in a “semi-cocked” position (approximately 90° abduction, 30° horizontal abduction, and 50° external rotation) when the stride foot contacts the ground, completing the early cocking phase.2

**EMG Analysis**

Electromyographic (EMG) measurements of upper extremity muscle involvement during the pitching motion express individual muscle activity as a relative percentage of the activity of that muscle during a maximal voluntary contraction (MVC), assigned a value of 100% activity. A range of 0% to 20% is considered low activity; 21% to 40%, moderate activity; 41% to 60%, high activity; and greater than 61%, very high activity.

DiGiovine and associates6 measured the activity of all upper extremity muscles during the windup to be low, below 21% of MVC. This low activity reflects the relatively small forces placed upon the shoulder during the windup phase. Few, if any, shoulder injuries occur during windup.

During the early cocking phase, the trapezius and serratus anterior demonstrate moderate to high activity. If the
EMG Analysis

The humerus maintains the same position of 90° to 100° of abduction that it did during early cocking. The scapula therefore does not undergo further elevation during this phase of the pitching motion. However, the opposing actions of the scapular protractor (serratus anterior) and retractors (middle trapezius, rhomboids, and levator scapulae) are still required to provide a stable base for rapid external rotation of the humerus.

Because of their anterior position, the subscapularis, pectoralis major, and latissimus dorsi provide stability to the anterior aspect of the glenohumeral joint. During the late cocking phase, when the humerus is externally rotated to 175°, these anterior shoulder muscles demonstrate high to very high activity. Eccentrically contracting, they apply an anterior force of about 310 N and an internal rotation torque of about 67 N-m, to carry out their stabilizing effect. In addition, the pectoralis major functions to horizontally adduct the humerus. The long head of the biceps contributes to anterior stability during late cocking. In the abducted and externally rotated position, the long head of the biceps limits anterior translation of the humeral head, acts as a restraint to excess external rotation, and alleviates strain on the inferior glenohumeral ligament. With the humerus abducted to 90°, the long head of the biceps induces a transverse shear force at the glenohumeral joint when external rotation exceeds 60° by compressing the humerus into the glenoid. This induced shear force provides constraint to humeral head displacements in the transverse direction. Kim and colleagues found significantly increased activity of the long head of the biceps in shoulders with anterior instability compared with normal shoulders in the same patients, with the greatest activity occurring in 90° and 120° of external rotation.

During the late cocking phase, the activity of the deltoid diminishes as the rotator cuff muscles increase their action. In fact, the primary forces generated during this phase are from the rotator cuff muscles themselves. The infraspinatus and teres minor show very high activity during the late cocking phase and are responsible for the extreme degree of external rotation. Their posterior position has a stabilizing effect, serving as a posterior restraint to limit anterior translation. Furthermore, by drawing the humeral head toward the glenoid, the infraspinatus and teres minor contribute to the stability of the shoulder joint. The rotator cuff muscles provide a compressive force of about 480 N. The supraspinatus is the least active of the rotator cuff muscles during the late cocking phase. As mentioned earlier, the level of shoulder abduction is largely unchanged. Also, at maximal external rotation, the supraspinatus is rotated posteriorly, rendering it less effective in providing the stabilizing, superior compressive force. Rotated superiorly during external rotation, the upper portion of the subscapularis demonstrates very high activity during this phase. This muscle provides some compression and support for...
creased laxity of these static stabilizers of the shoulder, as well as other overhand athletes, acquire in-
of motion at the shoulder needed to throw a ball, baseball

...tate enhanced work by the dynamic stabilizers of the

Shoulder Injuries
Anterior Instability and Posterior-Superior
(Internal) Impingement Syndrome
The stresses of maximal external rotation and horizontal
abduction that are placed on the shoulder can cause the
anterior shoulder structures to sustain microtrauma during
late cocking. Repetitive microtrauma to the anterior static
stabilizers of the shoulder can result in ligamentous stretch-
ing and hyperlaxity, leading to anterior translation of the
humeral head on the glenoid. Because of the precisely co-
ordinated firing patterns involved in dynamic stabilization,
improper mechanics or fatigue and weakness of the stabi-
izing musculature can increase the potential for instabil-
ity. If a pitcher tries to gain power by increasing the range
of external rotation, anterior shoulder muscles stretch even
further. The tremendous stresses resulting from both
stretch and eccentric muscle contraction can cause micro-
tears at the tissue insertions that accumulate with repeti-
tive throwing and thus further compromise the stabilizing
functions of the anterior shoulder muscles. Diminished
support from both the dynamic and static stabilizers of the
shoulder ultimately results in anterior instability.

In the older population, repetitive overhand activities
can lead to the development of overgrowth (spurring) of
the inferior surface of the acromion. Narrowing of the sub-
acromial space can result in outlet or subacromial impinge-
ment; that is, impingement of the bursal side of the rotator
cuff and biceps tendon on the coracoacromial arch. In the
young throwing athlete, however, impingement is usually
the result of anterior instability. When mild anterior insta-
bility first develops, the rotator cuff muscles compensate
by increasing their activity. With continued throwing, how-
ever, these dynamic stabilizers become fatigued, no longer
able to prevent anterior translation of the humeral head.
With the arm abducted and maximally externally rotated
during late cocking, this forward subluxation may cause
direct contact between the greater tuberosity of the humeral
head and the posterosuperior glenoid rim (Fig. 2). As a re-
result, the posterosuperior rotator cuff tendons and labrum
are pinched between these two structures, leading to the
internal impingement syndrome.19,24-29

On the other hand, internal impingement may be rela-
tively common and not restricted to patients with anterior
instability.28 In fact, it may be a physiologic variant in some
patients. Magnetic resonance (MR) imaging of seven vol-
teers with no history of shoulder instability demonstrated
contact between the greater tuberosity and posterosuperior
glenoid rim in all seven with the arm in full shoulder eleva-
tion and internally rotation, mimicking the impingement
sign.29 Cadavers with no history of damage or instability
that were frozen and sectioned with the shoulders in 60°
abduction, maximal external rotation, and horizontal ab-
duction showed contact between the undersurface of the

Figure 2 Posterosuperior (internal) impingement. With the arm
abducted and maximally externally rotated during late cocking,
forward subluxation of the humeral head may cause direct con-
tact between the greater tuberosity of the humeral head and the
posterosuperior glenoid rim. The rotator cuff tendons and pos-
terosuperior labrum may be pinched between the greater tuber-
osity and glenoid, leading to the internal impingement syndrome.
supraspinatus and the posterosuperior glenoid. Thus, it is possible that the pathologic changes of the internal impingement syndrome do not result from the contact per se, but from the repetitive motions and accumulation of microtrauma involved in overhead throwing.

Burkhart and associates proposed an alternative mechanism for internal impingement, suggesting that internal impingement is instead part of the spectrum of disorders associated with and secondary to Type II SLAP lesions.

Regardless of its underlying cause, internal impingement results in injury to a variety of shoulder structures. In a recent study of 41 symptomatic overhand athletes, Paley and coworkers found that 100% of patients had either contact between the rotator cuff undersurface and the posterosuperior glenoid rim or osteochondral lesions. Impingement of the supraspinatus and infraspinatus tendons against the posterosuperior glenoid rim resulted in undersurface rotator cuff fraying in 93% of patients. Full-thickness tears were not encountered in this study and are accepted as unusual findings in internal impingement. Posterosuperior and anterior labral fraying occurred in 88% and 36% of patients, respectively, while osteochondral lesions to the humeral head were found in 17%. The posterosuperior lesions consisted of grade II and III chondromalacia and full-thickness articular cartilage defects. In addition, 10% of patients had associated SLAP lesions while another 10% had Bankart lesions, all of which were associated with rotator cuff fraying.

Paley and coworkers also found that 5% of patients with symptomatic internal impingement had associated biceps tendon fraying. All of these patients also had associated rotator cuff pathology. The role of the long head of the biceps is increased in the unstable shoulder, and because of this, damage to the long head of the biceps can occur even without underlying internal impingement or associated rotator cuff pathology. As mentioned, the long head of the biceps contributes to anterior stability during late cocking. It’s role as an anterior stabilizer in abduction and external rotation becomes even more important in the unstable shoulder, helping to compensate for the instability. After creating a simulated Bankart lesion and applying an anterior force to the humerus, Itoi and colleagues demonstrated in cadaveric studies that the anterior displacement with the biceps loaded was significantly less than with any of the rotator cuff muscles loaded. They concluded that the long head of the biceps is more important than the rotator cuff muscles as stability from the capsulolabral complex decreases. Clinically, the increased strain on the long head of the biceps in the unstable shoulder can eventually lead to overuse injury and biceps tendon damage.

Most throwing athletes with shoulder dysfunction present with the chief complaint of pain, despite a wide range of underlying pathologic conditions. Pitchers with anterior instability typically present with shoulder pain during the late cocking or early acceleration phases, although pain is often present during other phases as well. Depending on the site of soft tissue damage, the pain can be localized along either the anterior or posterior aspect of the shoulder. Pain with progressive activity may point to a diagnosis of rotator cuff tendinitis secondary to impingement, while pain at rest or at night makes rotator cuff tears more likely. Occasionally athletes may also have associated instability symptoms, including feelings of the arm going dead or “coming apart.” However, throwers with occult subluxation often present with pain without any distinct instability symptoms.

**Physical Examination**

The physical examination must be directed toward localizing the particular area of shoulder dysfunction. Inspection of both shoulders should look for signs of muscular atrophy, bony deformity, and shoulder asymmetry. Atrophy, particularly of the infraspinatus, may represent chronic rotator cuff dysfunction or suprascapular nerve injury. Scapular asymmetries noted during bilateral arm motion can indicate deficiency of the serratus anterior. Because the serratus anterior maintains scapular positioning, dysfunctions of this muscle are a potential cause of impingement throughout the pitching motion. This is due to improper positioning of the glenoid for the abducting arm. Palpation of the shoulder can reveal signs of tenderness or crepitus. With rotator cuff impingement or tendinitis, tenderness may be elicited over the anterolateral acromion. Palpable crepitus with active or passive range of motion about the glenohumeral joint may indicate a torn labrum, acromioclavicular, or subacromial pathology.

The range of rotation is assessed with the shoulder in 90° abduction and various degrees of horizontal adduction. As mentioned earlier, the baseball pitcher normally acquires increased laxity in the static stabilizers of the shoulder. Therefore, increased external rotation of the throwing shoulder is expected when compared with the non-throwing shoulder. On the other hand, limitations in shoulder range of motion may indicate rotator cuff tendinitis, cuff tears, adhesive capsulitis, or osteoarthritis. Many asymptomatic throwers exhibit losses of internal rotation. Whether this represents a normal adaptive response to the repetitive stress of throwing or a pathologic contracture of the posterior capsule is not yet entirely clear. Cadaveric studies simulating posterior capsule contracture have demonstrated excessive anterior and superior translation of the humeral head. In a study by Burkhart and associates that included 44 pitchers with Type II SLAP lesions, all of the subjects were found to have tight postero-inferior capsules, evident on physical exam as marked loss of internal rotation with the arm abducted to 90°. These investigators concluded that a tight postero-inferior capsule would contribute to the development of, and therefore predispose to, Type II SLAP lesions.
Signs for impingement will often be obvious and can be elicited by using the Neer\textsuperscript{13} and Hawkins\textsuperscript{34} tests. During the Neer test, with the humerus maximally flexed and forcefully internally rotated, impingement appears to be on the undersurface of the cuff on the anterosuperior glenoid rim.\textsuperscript{19} In the Hawkins test, with the shoulder abducted, flexed, and internally rotated, the cuff appears to be compressed between the acromion and the glenoid rim\textsuperscript{19}; resistance to elevation and external rotation reproduces symptoms. Signs of occult glenohumeral subluxation, on the other hand, are often more subtle. Use of the apprehension test followed by the relocation test has proved to be the most sensitive means of detecting occult anterior subluxation.\textsuperscript{32} While the patient is supine, the arm is abducted 90° and maximally externally rotated. Posterior shoulder pain elicited by an anterior directed force on the proximal humerus during the apprehension test, followed by relief of pain with a posterior directed force on the proximal humerus during the relocation test, are considered diagnostic for anterior instability.

Resistance maneuvers in abduction and external rotation may elicit symptoms of weakness. Furthermore, these maneuvers may alert the examiner to the need for strengthening of these muscles during rehabilitation.

Standard radiographs usually add little information in the evaluation of young athletes with anterior instability. The Stryker notch view may be employed in an attempt to demonstrate a Hill-Sachs lesion.\textsuperscript{35} However, no single view consistently reveals the presence or extent of a Hill-Sachs lesion. The West Point axillary view is useful for identifying the presence of glenoid rim pathology, such as a Bankart lesion.\textsuperscript{35} Magnetic resonance (MR) imaging permits accurate imaging of the rotator cuff, allowing diagnosis of full-thickness tears and delineation between tendinitis and partial-thickness tendon tears.\textsuperscript{36} Improvements in resolution and imaging techniques now allow for a better assessment of labral pathology and capsular volume.

**Treatment**

Treatment is directed toward alleviating pain, restoring motion, and increasing strength to improve the dynamic stability of the glenohumeral joint. The majority of throwers respond well to this nonoperative program. Because the constituents of the capsulolabral complex have no contractile elements, once they are over stretched, no effective noninvasive treatment exists to restore stability to these elements. Given that most injuries result from chronic, repetitive microtrauma, an initial period of rest is recommended. Pain relief can be addressed initially with nonsteroidal anti-inflammatory medications. Some investigators have recommended up to three cortisone injections about the shoulder for recalcitrant pain and inflammation.\textsuperscript{24} However, cortisone injections may not be indicated in the young athlete because of the potential for tendon damage.\textsuperscript{12}

As mentioned earlier, loss of internal rotation due to posterior capsular contracture is not uncommon in the symptomatic pitcher. Graduated stretching in adduction and internal rotation should be performed until symmetric motion is achieved.

Increased glenohumeral translation resulting from minor to moderate degrees of capsular stretch can usually be compensated for by improving dynamic stabilization.\textsuperscript{12} The strengthening phase of rehabilitation is directed toward the muscles involved in the pitching motion. Rotator cuff strengthening includes internal and external rotation exercises performed at the side. Especially important for glenohumeral stability, the supraspinatus can be isolated using resistive exercises with the arm abducted 90°, internally rotated, and forward flexed 30°. The scapular rotators can be strengthened with shoulder shrugs for the upper trapezius, push-ups for the serratus anterior, and chin-ups or pull downs for the latissimus dorsi. Strengthening of the long head of the biceps, coracobrachialis, and anterior deltoid can be achieved with forward flexion exercises, limiting flexion to 90°. Finally, using horizontal adduction exercises with the arm abducted to 90°, the pectoralis major and anterior deltoid can be targeted. Regardless of the type of exercises being performed during rehabilitation, patients with instability should avoid hyperextension or abduction with external rotation.

Failure of nonoperative treatment is defined as a lack of definitive progress after three to four months or an inability to return to active competition by six months.\textsuperscript{12} When rehabilitation fails to relieve symptoms and improve performance, surgical intervention may be warranted. Surgical treatment begins with an examination under anesthesia to confirm the presence and direction of instability. Arthroscopic evaluation may reveal anteroinferior capsular lesions, anterior labral damage, humeral head subluxation, or undersurface tears on the supraspinatus or infraspinatus. Normally, external rotation of the humerus creates tension in the glenohumeral ligaments, especially the inferior glenohumeral ligament. With capsular stretch, these ligaments become lax or attenuated so that when the humerus is externally rotated the arthroscope may be easily passed between the humeral head and the anterior glenoid rim in the region of the anterior band of the inferior glenohumeral ligament, a finding known as the drive-through sign (Fig. 3A).\textsuperscript{36} If only minimal instability is evident (much of which is a normal characteristic of the pitcher’s shoulder), treatment may involve arthroscopic debridement of the cuff pathology with the hopes of stimulating a healing response, and minimal efforts at decompression.\textsuperscript{34} If distinct subluxation due to excessive capsular or ligamentous laxity is evident, then arthroscopic or open stabilization may be indicated (Fig. 3B).

With a success rate of 95% and better, the anterior capsulolabral reconstruction (ACLR) is the treatment of choice in throwers with anterior instability in whom non-
operative treatment has failed.19 The procedure repairs and reinforces the anterior capsule and, if necessary, the anterior glenoid labrum, at the point of instability. The shoulder is first exposed using a typical deltopectoral approach. With the arm in external rotation, a position that protects the long head of the biceps, a horizontal incision is made in the lower third of the subscapularis tendon. Splitting, rather than transecting, the subscapularis minimizes the risk of postoperative shortening of the tendon.12 After extending the subscapularis incision laterally into the tendon and medially past the glenoid margin, the capsule is exposed and incised horizontally, superior to the anterior band of the inferior glenohumeral ligament. At this point, the labrum is examined to assess for labral pathology. If the labrum is detached, the capsulotomy is extended onto the glenoid neck. A subperiosteal flap containing the periosteum, inferior labrum, and inferior glenohumeral ligament, is then elevated. After abrasion of the glenoid neck down to bleeding bone, the labrum is secured to the articular margin using bone anchors. The horizontal capsular incision can then be imbricated by shifting the inferior capsular flap superiorly, thereby correcting the redundancy of the capsule.

Altcheck and colleagues40 described their T-plasty modification of the ACLR involving a T-shaped incision made in the anterior capsule, with advancement of the inferior flap superiorly and the superior flap medially (Fig. 4). This serves to reduce the capsular laxity both anteriorly and inferiorly. Particular care is taken not to shorten the capsule too much so that range of motion and function are not compromised. Jobe and associates19 suggested that the arm be positioned in 90° of abduction and full external rotation (the shoulder position achieved during the late cocking phase) before the capsular sutures are tightened, thus ensuring enough capsular laxity for normal throwing. If there is no labral detachment, the horizontal capsular incision is simply imbricated, shifting the inferior capsular flap superiorly.

Following closure of the capsule, the subscapularis is closed with absorbable sutures. In high performance pitchers, the arm is often splinted in approximately 90°.

**Figure 3** Shoulder capsular laxity. A. Arthroscopic drive-through sign. With shoulder laxity, the glenohumeral ligaments become lax or attenuated. With the humerus externally rotated, the arthroscope may be easily passed between the humeral head and the anterior glenoid rim in the region of the anterior band of the inferior glenohumeral ligament, a finding known as the drive-through sign. Note the humeral head on the left and the glenoid labrum on the right. B. The same patient after an arthroscopic capsular shift using a nonabsorbable suture.

**Figure 4** Anterior capsulolabral reconstruction (ACLR). Using a deltopectoral approach, the capsule is exposed and a T-shaped incision is made in the anterior capsule. The incision is then imbricated with advancement of the inferior flap superiorly and the superior flap medially. This serves to reduce the capsular laxity both anteriorly and inferiorly.
of abduction, 45° of external rotation, and 30° of horizontal adduction, a position that allows capsular healing in a position of function and facilitates early rehabilitation efforts in achieving full range of motion. Except during rehabilitation exercises, the splint is worn full-time for two weeks.

Rehabilitation

Since muscle attachments and proprioceptive fibers are not violated during the operative procedure, full range of motion and strength can be quickly regained through immediate postoperative rehabilitation. Passive range of motion and active assisted range of motion exercises are utilized, and full range of motion is usually achieved within 2 ½ months. Strengthening exercises are used throughout the rehabilitation period, emphasizing the rotator cuff muscles, shoulder rotators, and anterior shoulder muscles. These exercises are continued for a minimum of one year. Return to throwing can be resumed when the player has full range of motion that is pain free, normal strength, and confidence in the shoulder. Alternatively, at the fourth to sixth postoperative month, if isokinetic testing to evaluate strength and endurance are adequate (at least 80% of the shoulder capacity), the patient may begin a throwing program. The throwing program is graduated, beginning with light tossing and progressing over a period of four to six months to full-velocity activity. Approximately eight to ten months after surgery, the patient usually reaches the point in rehabilitation when strength, endurance, and rhythm come together and performance is regained.

Arthroscopic advances, including suture and thermal capsulorrhaphy, have become popular in the treatment of instability. Cole and coworkers recommend preoperative examination under anesthesia and arthroscopic evaluation to determine if arthroscopic or open treatment is indicated. Based on a prospective, nonrandomized comparison, they recommend arthroscopic Bankart repair for patients with isolated anterior instability and a discrete Bankart lesion, and open capsular shift for patients with anterior and inferior instability and capsular laxity. With proper pre-operative selection, the results of arthroscopic techniques are comparable with those of open procedures with respect to recurrent instability, range of motion, need for reoperation, and ability to return to sports. In addition, arthroscopic techniques allow for shorter hospital stays, reductions in cost and postoperative pain, improved cosmesis, and quicker recovery time.

Bicipital Tendinitis

Bicipital tendinitis is a relatively common cause of shoulder pain in the throwing athlete. In the older population, bicipital tendinitis is most often a component of the impingement syndrome. In the young athlete participating in overhead activities, however, damage and inflammation to the tendon and its sheath may also result from repetitive trauma to the long head of the biceps due to overuse in-
jury. Repetitive overriding of the tendon of the long head of the biceps brachii over the lesser tuberosity during external rotation-abduction can lead to bicipital tendinitis in isolation of other pathologic processes. The accumulation of injury to the tendon can eventually lead to tendon rupture.

Athletes with bicipital tendinitis will complain of pain over the anterior aspect of the shoulder. Pain may be localized to the bicipital groove, radiate distally to the biceps muscle belly, or radiate proximally to the deltoid or base of the neck. Although a history of recent trauma or overexertion of the shoulder may be present, many cases involve the insidious onset of shoulder pain. Indeed, the severity of the pain is usually related to the duration of the pathologic process.

**Physical Examination**

The most consistent finding on physical examination is tenderness while palpating the biceps tendon along the intertubercular groove. Using Speed’s test, with the elbow extended and the forearm supinated, pain localized to the bicipital groove may be elicited while the shoulder is flexed against resistance. Yergason’s test may elicit shoulder pain on resisted supination of the forearm with the elbow flexed at 90°. The absence of these positive signs does not preclude a diagnosis of bicipital tendinitis. When impingement is not the cause of the inflammation, impingement signs are normally absent. While full range of motion is present in some cases, range of motion may be limited due to pain. In the latter case, however, a narrow range of comfortable motion may still be present.

**Treatment**

The initial treatment approach consists of an initial period of rest and nonsteroidal anti-inflammatory medication. Steroid injections into the bicipital groove should be avoided because of the possible promotion of tendon rupture. Even with steroid injections, relief of symptoms is only temporary. Rehabilitation to preserve range of motion and muscle strength is begun as symptoms subside. Strenuous muscle resistance exercises, however, should be avoided. Conservative treatment is usually successful. Recurrent or refractory symptoms are indications for surgical repair in the young athlete.

**EMG Analysis**

Functioning as a fulcrum for the high angular velocities and torques involved with this phase, a stable scapula is maintained by very high activity from all of the scapular muscles. Energy transfer from the legs and rotation of the trunk combined with augmentation by the upper extremity muscles result in the large angular velocity during the acceleration phase. The latissimus dorsi and pectoralis major are the primary muscles that actively contribute velocity to the ball. Bartlett and colleagues...
demonstrated that these were the only upper extremity muscles to have a positive correlation between peak torque developed in isokinetic testing and pitching velocity. While both the latissimus dorsi and pectoralis major generate large internal rotation torques about the shoulder, the latissimus dorsi is anatomically positioned to generate the greater torque. As shown with EMG studies, the pectoralis major demonstrates high activity (54% of MVC) during the acceleration phase, while the latissimus dorsi demonstrates very high activity (88% of MVC). Working in concert with the latissimus dorsi and pectoralis major, the subscapularis exhibits very high activity as well, functioning as a steering muscle to position the humeral head precisely in the glenoid (a relationship similar to that between the deltoids and the supraspinatus during shoulder abduction). The fine control exerted by the subscapularis serves to prevent subluxation of the humeral head during rapid internal rotation. The teres minor, on the other hand, appears to form a force couple with the pectoralis muscle to stabilize the shoulder joint. As the pectoralis major contracts at the relatively high elevations for adduction and internal rotation, the teres minor provides a stabilizing posterior restraint to limit humeral head translation. The teres minor and infraspinatus have different levels of muscle activity, high for the former and moderate for the latter. In addition, the teres minor demonstrates increased activity when the humerus is abducted or extended, as it is in the beginning of the acceleration phase. This may have clinical relevance, since posterior cuff tenderness in baseball pitchers can frequently be isolated to the teres minor. As the humerus is internally rotating, the posterior deltoid is positioned to carry out the horizontal abduction that occurs during the acceleration phase.

**Shoulder Injuries**

**Subacromial Impingement**

Impingement in the young throwing athlete is most often secondary to anterior instability. Pure impingement without underlying instability may occasionally develop in the throwing athlete over 35 years of age. In these athletes, repetitive overhand throwing leads to overgrowth (spurring) of the inferior surface of the acromion and narrowing of the subacromial space. This can lead to mechanical compression of the rotator cuff, centered primarily on the supraspinatus insertion onto the greater tuberosity, against the undersurface of the anterior one third of the acromion and the coracoacromial ligament. The area of impingement on the greater tuberosity may include the long head of the biceps tendon anteriorly and the infraspinatus insertion posteriorly. The relatively poor vascularity of the supraspinatus tendon limits the healing potential in this area. Inflammation with subsequent thickening and fibrosis of the subacromial bursa further narrows the subacromial space, worsening the impingement.

In the baseball pitcher, impingement occurs with the arm in 90° or greater abduction, with movement into an internally rotated and horizontally adducted position. Thus, shoulder pain is felt during the late acceleration phase of the throw. On physical examination, tenderness on palpation may be demonstrated over the acromion or subacromial space. Palpable crepitus with active or passive range of motion about the shoulder may indicate dense scarring of the subacromial bursa, subacromial osteophytes, or an actual rotator cuff tear. Impingement signs are a common finding, while the apprehension sign should be negative. Injection of the subacromial space with 1% lidocaine will often relieve the symptoms and help confirm the diagnosis. Additional symptoms and signs of bicipital tendinitis and rotator cuff pathology may also be present.

Standard radiographs of shoulders with subacromial impingement may be negative. When present, positive findings include narrowing of the subacromial space, subacromial spurs and undersurface osteophytes, acromioclavicular osteoarthrosis, and cystic or sclerotic changes of the greater tuberosity. Magnetic resonance imaging should be performed in order to ascertain rotator cuff pathology.

Initial treatment includes rest and nonsteroidal anti-inflammatory medications. Gentle passive range of motion exercises should be performed to prevent stiffness, normalize shoulder motion, and increase internal rotation. Strengthening exercises are initiated with isometric and isotonic exercises, and progress to eccentric and aggressive strengthening. In addition to rotator cuff strengthening, the scapular muscles must also be addressed. If symptoms persist after three to six months of nonoperative treatment, arthroscopic acromioplasty may be indicated. Subacromial decompression may be further achieved with excision of the coracoacromial ligament. During arthroscopy, any associated rotator cuff pathology is repaired.

It should be reiterated that in the younger pitcher, in whom impingement is most commonly secondary to instability, bone decompression or acromioplasty is rarely indicated. Treatment in these patients should instead address the underlying instability to treat the secondary impingement.

**Summary**

The extreme range of motion at the shoulder, the high angular velocities and torques, and the repetitious nature of the pitching motion combine to make the shoulder vulnerable to injury during the baseball pitch. An understanding of the biomechanics that contribute to shoulder injuries during each phase of the pitching motion can facilitate the athlete’s diagnosis, treatment, and rehabilitation. Common injuries that occur during the late cocking and acceleration phases of the pitch include anterior instability and impingement, bicipital tendinitis, and subacromial impingement. Nonoperative treat-
ment consisting of an initial period of rest and NSAIDS, followed by physical therapy and a gradual return to activity, is usually successful. When this approach fails, surgical intervention, either arthroscopic or open, may be necessary. Physical therapy and rehabilitation are directed toward restoring the integrity and strength of the dynamic and static stabilizers of the shoulder joint, yet preserving the range of motion necessary for performance. Through rehabilitation, the dedicated athlete can often return to the pitching mound at his previous level of performance.

References

50. Speed JS: Personal communication. 1952.