Current Concepts

Ulnar Collateral Ligament of the Elbow

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Recent advances in the diagnosis and treatment of the overhead athlete's elbow has led the medical community to understand that the ulnar collateral ligament (UCL) of the elbow is more commonly injured than originally thought. Injury can result in secondary symptoms and problems in other regions of the elbow. Sports requiring an overhead motion, such as throwing a ball, hitting a ball overhead, or serving a tennis ball, imparts a valgus stress on the elbow that is resisted by the UCL. Throwing sidearm or hitting a forehand in tennis, squash, or racquetball may also impart a valgus stress to the elbow. Repeated or excessive valgus stress places a force on the UCL that may result in injury to the ligament. Injury to the UCL may result in problems in other areas of the elbow, including the ulnar nerve, the flexor-pronator musculotendinous unit, the radiocapitellar joint and the posterior compartment of the elbow, in addition to being a cause of loose bodies within the elbow. This article reviews the anatomy, biomechanics, and pathophysiology of injury to the UCL and injuries to the other structures that result from UCL injury. Also reviewed are patient history, examination techniques, tests that help confirm the diagnosis of UCL injury, and treatment of the injured UCL. **Key Words:** Ulnar collateral ligament—Medial—Sprain—Throwing

Pain on the medial aspect of the elbow may result from valgus instability caused by acute or chronic ulnar collateral ligament (UCL) disruption or attenuation. In 1946, Waris[1] first recognized and described UCL tears in 17 javelin throwers. Subsequently, early reports suggested that UCL injury is a rare problem, but more recently, possibly as a result of better understanding of the problem and ability to diagnose injury to the UCL and/or the increased awareness of this clinical problem, it is clear that this injury is not uncommon in athletes.

Overhead athletes, such as those who participate in baseball (particularly pitchers), tennis, water polo, volleyball, ice hockey, golf, and football (quarterback), subject their elbow to major valgus forces. Valgus forces that occur during overhead sports are responsible for many problems in the thrower's elbow, beginning with injury to the UCL. Continued throwing with an UCL-injured elbow results in repetitive valgus force resulting in stresses to other parts of the elbow that consequently develop lesions that may produce a variety of symptoms. This Current Concepts review provides a brief overview of the anatomy and biomechanics of UCL injury, focusing specifically on the areas affected by the forces of throwing or serving. It also discusses the pathophysiology of repetitive valgus injuries, details the history, physical examination, and ancillary tests to confirm the diagnosis of UCL injuries, and lists the treatment options available.

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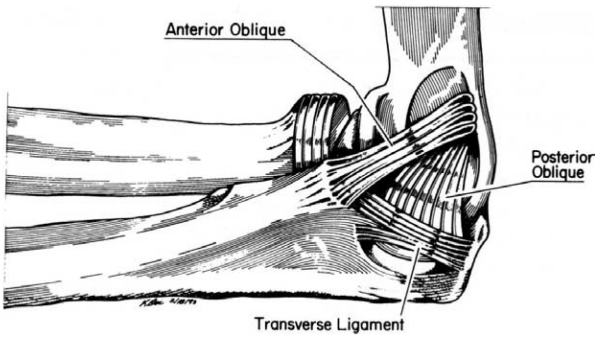

Figure 1. UCL complex of the elbow. (Reprinted with permission.[40])

FUNCTIONAL ANATOMY AND BIOMECHANICS

A concise review of the pertinent anatomy and biomechanics as it relates to the UCL is important in understanding the pathophysiology of UCL injury and the secondary lesions that occur in individuals with UCL laxity. A detailed review of the anatomy and biomechanics of the elbow is beyond the scope of this article, and the reader is referred to recent reviews on these topics.[2-4]

Ligamentous Anatomy: Medial

The UCL complex consists of 3 ligaments (Fig 1): the anterior oblique (AOL), posterior oblique (POL), and transverse ligaments. The origin of the AOL and POL is from the anteroinferior surface of the medial epicondyle.[5]

The AOL is the strongest component of the UCL.[6] The AOL is 4- to 5-mm wide[7] and is histologically divided into 2 parts, 1 within the medial capsule and 1 on the superficial surface of the capsule that also serves as a partial origin of the flexor carpi superficialis.[8] The AOL is the primary restraint and stabilizer to valgus stress.[6,9-11] The origin of the AOL is inferior to the axis rotation[12] and inserts 18 mm distal to the coronoid tip, along the medial aspect of the coronoid process, near the sublime tubercle (Fig 2).[7,9] The AOL is functionally composed of anterior bands (AB) and posterior bands (PB) that provide a reciprocal function in resisting valgus stress through the range of flexion-extension motion.[6,14] Recent studies have refuted the concept of an isometric fiber between the AB and PB.[13,15]

The POL is a fan-shaped thickening of the capsule (Fig 1) that originates from the medial epicondyle, forms the floor of the cubital canal, and inserts along the midportion of the medial margin of the semilunar notch.[13] It is 5- to 6-mm wide at its midportion, is thinner than the AOL, and exists within the layers of the medial elbow capsule.[8]

The transverse ligament (Cooper's ligament) connects the inferior medial coronoid process with the medial tip of the olecranon.[13,14] It is generally believed to have little or no contribution to valgus stability.[12-14]

Biomechanical Forces

The magnitude and degree of force transmitted across the elbow joint varies based on specific factors which include loading configuration and angular orientation of the joint (degree of elbow flexion).[13,14] Activities of daily living produce about 50% body weight across the elbow joint, although forces have been calculated up to 3 times body weight, peaking at about 90° of elbow flexion.[17-20]

The athlete, however, is most often exposed to

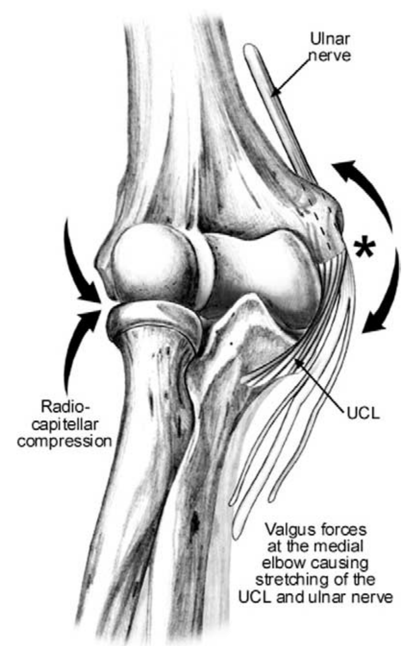

Figure 2. Valgus stress to the elbow imparts a tensile force to the medial elbow, resulting in injury to the UCL. Other medial structures, such as the flexor-pronator muscles, can be injured by repeated eccentric contraction and while attempting to provide dynamic stability to the medial elbow. The ulnar nerve is susceptible to injury from these tensile forces as well as compression within a narrowed cubital tunnel, secondary to the scarring within the ligament and osteophytes. With continued valgus stress, the radiocapitellar joint is compressed, which may result in chondromalacia, osteophyte formation, and eventually, loose bodies. (Reprinted with permission.[94])

severe, chronic repetitive valgus stresses. Although bony articulation contributes significantly to resisting these stresses with the elbow near full extension (flexed less than 20°) or flexion (greater than 120°),[9,14,21,22] the major restraint to valgus stress between these 2 ranges is the UCL complex. The anterior half (AB) of the AOL functions as a checkrein from full extension to 85° of flexion, while the PB is taut with elbow flexion beyond 55°. As previously noted, the AB is the most important stabilizer of the UCL complex for valgus throwing forces. The POL functions with the elbow flexed beyond 90°.[21-24] When the UCL is completely sectioned, elbow laxity is greatest at 70° of flexion.[9,16,25]

Whereas the lateral bony structures have clearly been shown to be a secondary stabilizer to valgus stress,[10,11] the relationship between UCL injury–valgus laxity and the olecranon within its fossa has been the subject of debate. A report on professional baseball players who underwent olecranon debridement stated that 25% developed valgus instability and eventually required UCL reconstruction.[26] This observation suggests that both the olecranon and the UCL contribute to valgus stability. A recent biomechanical study suggests olecranon resection subjects the UCL to greater strain and places the UCL at increased risk of injury.[27] Kamineni et al.[28] also showed the strain in the AOL is increased with increasing posteromedial olecranon resection beyond 3 mm. Ahmad et al.[29] found that UCL injury results in contact alterations in the posterior compartment that lead to osteophyte formation. On the other hand, Andrews et al.[30] found no increase in strain in the anterior portion of the elbow UCL with removal of up to 8 mm of bone from the medial olecranon.

The flexor carpi ulnaris lies directly over the UCL and is believed to be the primary dynamic contributor to valgus stability, although the flexor digitorum superficialis (FDS) may also support valgus stability in greater degrees of extension because the FDS takes part of its origin off the UCL.[8,31,32] The wedge shape of the olecranon central ridge within the trochlea provides additional varus–valgus stability with the addition of muscular joint compression forces across the elbow (from the muscles that cross the joint and are contracting during activity).

PATHOPHYSIOLOGY OF THE THROWER'S ELBOW

Valgus stress as a result of throwing produces tensile or distraction forces to the medial elbow. Chronic tensile stress is initiated by the repetitious high-velocity nature of overhead sports (e.g., baseball pitch, tennis serve, javelin throw, football pass, hockey slap shot, and volleyball spike) and often predisposes the elbow to overuse syndromes.[33] Many of these sports require similar motion and mechanics: rapid forceful extension of the elbow, frequently accompanied by valgus stress and pronation of the supinated forearm.[3] The normal valgus carrying angle of the elbow may predispose the medial aspect of the elbow to valgus overuse injuries. The velocity, power and repetitious nature of the throwing motion all contribute to the repeated microtrauma, particularly during the late cocking and early acceleration phases of the throwing cycle.[33] Biomechanical studies have estimated that the medial elbow shear forces exceed 300 N, compressive forces exceed 900 N during throwing, and elbow extension occurs at up to 2,500° per second.[33,34] In tennis, elbow extension velocities occur at approximately 1,300° per second.[35] Valgus stress applied to the elbow during the acceleration phase of throwing is 64 N-m,[33,34] and more than 60 N-m with the tennis serve.[36,37] These estimated forces exceed the known ultimate tensile strength of the UCL from cadaveric specimens (33 N-m).[38]

The forces at the elbow caused by recurring valgus stress result in (1) traction of the medial sided structures of the elbow (Fig 2), (2) compression of the lateral side of the elbow, and (3) medially directed posterior shear and compression of the posteromedial olecranon (Fig 3). The medial traction forces may result in tensile injury to the soft tissues of the medial elbow, including the UCL, ulnar nerve, and the components of the flexor-pronator musculotendinous complex. The exception to this is the immature athlete in whom the physis (medial epicondylar apophysis) is the weakest link in the adolescent musculoskeletal system and thus is most susceptible to injury.[39,40] The bony tissues of the lateral elbow (radiocapitellar joint) are inundated with repetitious compressive forces, accentuated when there is UCL laxity.

Effects on the Medial Elbow

Medial elbow structures are primarily susceptible to injury because of the valgus forces that are associated with repetitive throwing. The UCL is particularly at risk of injury because of repetitive tensile (valgus) overload as seen with overhead throwing sports and valgus stress with tennis serving and forehands, golfing, and hockey slap shots. With UCL injury, tensile forces will then be imparted to other structures of the

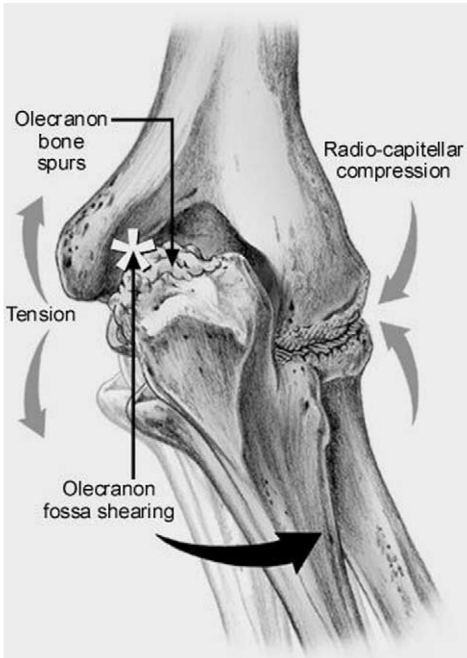

FIGURE 3. Posteriorly, the olecranon is subjected to medial shearing forces with valgus stress, which may be accentuated by increased valgus laxity, resulting in valgus extension overload, with osteophyte formation and loose bodies. (Reprinted with permission.[94])

medial elbow, including the flexor-pronator musculotendinous unit and the ulnar nerve.

As noted earlier, the primary dynamic stabilizer to valgus stress is the flexor-pronator muscle mass, particularly the flexor carpi ulnaris and FDS.[31,32] With repetitive valgus stress as a result of throwing, these muscles may fatigue, imparting increasing stress to the UCL, producing microtraumatic ligamentous injury resulting in stretching of the ligament (Fig 2). Also as previously noted, the UCL is the most important static stabilizer to valgus stress to the elbow in the arc between 30° and 120° elbow flexion, greater than the range of motion needed from the elbow during throwing.[9,33] As a result, the UCL is particularly at risk of injury, including microtears or frank tears, from excessive repetitive valgus force during throwing and overhead sports, depending on the magnitude of force and rate of loading of the ligament.

Further, fatigue of the medial muscles may result in inflammation and injury to the musculotendinous unit of the medial elbow.[41] This may result in medial epicondylitis in adults and medial epicondylar apophysitis or avulsion in the skeletally immature thrower.[40,41] An athlete may be even more susceptible to these problems if there is concomitant laxity of the UCL because of repeated injury resulting in increased dependence on these dynamic stabilizers. There are also reports of cases of flexor-pronator muscle avulsion injuries associated with UCL tears, demonstrating the agonistic function of these structures.[42,43] Chronic traction injury to the UCL may result in thickening of the ligament and/or traction osteophytes at its insertion on the ulna. Chronic UCL laxity may also result in shear forces at the posteromedial elbow that may produce osteophytes and loose bodies in the posterior compartment of the elbow.

Pressure within the ulnar nerve has been found to be elevated to 3 times more than normal with the elbow flexed at 90° and the wrist extended, the position of late cocking and early acceleration.[44,45] The intraneural pressure elevation is felt to be the result of physiologic stretching of the nerve combined with compression by the flexor carpi ulnaris aponeurosis.[46] With further elbow flexion, wrist extension, and shoulder abduction, which can occur with throwing, this pressure can be elevated to as much as 6 times the resting normal intraneural pressure.[45,47] Further, ulnar nerve has been shown to elongate an average 4.7 mm with elbow flexion and can be displaced by more than 7 mm by the medial head of the triceps.[48,49] As a result, the cubital tunnel narrows 40% to 55% with elbow flexion, resulting in compression of the ulnar nerve.[44,48] The cubital tunnel may be encroached further by a variety of associated pathologies commonly seen in overhead athletes, including osteophytic spurs, loose bodies, synovitis, thickening of the arcuate ligament, chronically inflamed and/or thickened UCL or calcification of the UCL, all potentially resulting in further compression of the ulnar nerve.[49-51]

Traction neuritis may be made worse by the valgus forces associated with throwing activities. With an incompetent or lax UCL, the medial joint widens with valgus stress, imparting a tensile stress to the nerve as it is stretched beyond its normal elongation. It is not uncommon for professional baseball and tennis players to have fixed elbow flexion and valgus deformities; static malalignments that further predispose them to ulnar nerve problems. The end result of excessive traction is fibrosis from direct injury and possibly ischemia of the nerve caused by prolonged or repeated elevation of pressures and stretching injury.[46]

Effects on the Lateral Elbow

Valgus stress to an elbow with an attenuated UCL may result in compression of the bony structures of the lateral elbow functioning as a secondary stabilizer. In the adult, valgus stresses in the case of a lax UCL may result in a radiocapitellar overload syndrome (Fig 2). Repetitive compressive forces to the radiocapitellar joint can result in radial head abutment against the capitellum. This chronic, repetitive compressive force may result in chondromalacia of the radiocapitellar joint surfaces followed by cartilage and then bony degeneration. Persistent radiocapitellar compression may eventually result in osteochondral fracture and the production of loose bodies within the joint. In the skeletally immature athlete, it is proposed that this may be clinically manifest as capitellar osteochondritis dissecans, possibly as a result of interruption of the subchondral blood flow caused by repeated compressive forces.[52,53]

Effects on the Posterior Elbow

Throwing forces may also result in posterior elbow pain as the olecranon is repeatedly and forcefully driven into the olecranon fossa. Typically, a valgus stress causes shearing posteriorly, resulting in the olecranon impinging against the medial wall of the olecranon fossa. Ahmad et al.[29] reported that UCL injury results in contact alterations in the posterior compartment that lead to osteophyte formation. The results of this study suggest that osteophyte formation may be caused by subtle UCL injury or increased valgus laxity, due to increased shear forces to the posteromedial elbow (Fig 3). Compounding this posterior impingement is the bony hypertrophy of the distal humerus and proximal ulna that is commonly seen in those athletes involved in sports such as tennis and baseball.[54,55]

Hypertrophy of the distal humerus decreases the size of the olecranon fossa. The reduction in fossa size makes less olecranon translation necessary to result in bony impingement. Additionally, proximal ulna hypertrophy also decreases the free space between the olecranon fossa and the olecranon, allowing for impingement to occur with lesser degrees of medial laxity and posterior shearing. In addition, the fixed valgus deformity often seen in throwing athletes who have played for many years also positions the medial olecranon closer to the medial wall of the olecranon fossa. Thus, less translational motion (and thus UCL laxity) is needed before the olecranon contacts the distal humerus and results in posterior impingement and valgus extension overload. Moreover, the repeated high-extension velocities may result in impaction of the olecranon tip within the fossa. The intra-articular tip of the olecranon causes localized inflammation. With repetitive impaction of the olecranon tip within the fossa, chondromalacia and osteophyte formation can occur. With persistent impingement and shear forces, these osteophytes may break off and become loose bodies within the joint.[56] Loose bodies may cause mechanical symptoms, such as blocking flexion or extension, or may produce a synovitic reaction resulting in an effusion and stiff elbow. These forces may also result in other olecranon injury, including stress reaction, stress fracture, or apophyseal injury in the skeletally immature ball player.[57-60]

UCL INJURY DIAGNOSIS

History

Evaluation of the athlete with a suspected injury of the UCL begins with an assessment of the patient's sport, level of participation, hand dominance, and affected elbow. It should be ascertained if their elbow injury occurred acutely and whether they have had previous elbow problems. Certainly, it is important to know if the athlete has had previous elbow injections or surgery. For throwers, the style of their mechanics, normal and current velocity (ball velocity before and after the onset of elbow pain), and accuracy after onset of elbow pain as well as a determination of when the symptoms occur during the specific phase(s) of throwing should be recorded. For baseball pitchers, types of pitches used, pitch count, number of innings pitched, and types of pitches affected by the elbow pain are also documented. Because of the importance of the kinetic chain in the development of ball velocity,[2] it is important to know if the athlete has had any recent pain, injury, or surgery in the segments more proximal to the elbow, such as the ipsilateral shoulder, back, hip, knee, or ankle.

Athletes susceptible to UCL injuries include baseball players (particularly pitchers), javelin throwers, water polo players, volleyball players, tennis players, golfers, volleyball players, arm wrestlers, collegiate wrestlers, hockey players, and gymnasts. Athletes with an acute UCL rupture will often complain of sudden onset of pain with or without a popping sensation that has usually occurred during a particular throw. They may also note an inability to continue throwing after the injury. Symptoms of ulnar nerve irritation may also be present after an acute UCL tear due to the hemorrhage and edema from the ligament injury irritating the nearby nerve.

Chronic valgus instability may result from complete disruption or attenuation of the UCL. Athletes with chronic valgus instability often complain of pain or soreness along the inner elbow during throwing. Overuse is the most common cause of UCL injury in the overhead athlete.[61] A common history reported by the athlete with chronic valgus instability is of repeated bouts of inner elbow pain during and after throwing that often responds to conservative management. Ultimately, these athletes present when they are unable to throw the ball at over 75% velocity because of this pain.[61] This may be reported by the player as a loss of "zip" or "pop" on the ball. Occasionally, the athlete with chronic UCL injury may note a distinct, single isolated episode of "giving way" or sudden severe medial elbow pain that precipitated their presentation to the physician. This often represents the final injury to the previously injured UCL. Injury to the UCL has been characterized in 4 stages: (1) edema and inflammation, (2) ligament fiber dissociation, (3) ligament calcification, and (4) ossification in chronic cases. Athletes most commonly report pain during the acceleration phase of throwing, and pain at ball release/point of impact in hitting the ball is the second most common point in time of elbow symptoms.[42]

Because of the chronicity of the instability, the athlete may also describe other symptoms about the elbow as a result of injury to structures serving as secondary restraints, as described above. These symptoms include ulnar nerve irritation, medial epicondylitis, and/or symptoms of loose bodies, including mechanical symptoms such as locking. Athletes with ulnar neuritis may report symptoms similar to those in the general population with this entity. However, athletes usually present with early ulnar nerve symptoms described as medial joint line pain and/or clumsiness or heaviness of the hand and fingers associated with, or exacerbated by, throwing or overhead activity. The athlete may also note numbness and tingling of the little and ring fingers, at first with overhead activity only, and later with minimal activity. Medial elbow pain may radiate along the ulnar side of the forearm to the hand. Ulnar nerve symptoms often will improve or disappear with rest, but recur when activity is resumed. These symptoms can increase in frequency and earlier when returning to throwing if left untreated. Athletes with symptomatic loose bodies may complain of catching or locking of the elbow. They may note that manipulation of the elbow is necessary to release or unlock it.

Physical Examination

General examination includes inspection, palpation, and active and passive motion of both upper extremities (elbows, wrists, and hands), in addition to a thorough neurovascular examination. The examination should include assessment of the shoulder and scapula because pain or dysfunction of these areas may result in altered throwing mechanics and potential UCL injury, as noted above in relation to the kinetic chain.[2] Further, an elbow assessment is not complete without evaluation of the neck, to rule out referred pain. Examination for the presence of the palmaris longus is important for those that may need UCL reconstruction.

On physical examination, athletes with UCL injury may have point tenderness localized 2 cm distal to the medial epicondyle. Those with an acute UCL injury will usually have pain at the medial elbow and may have laxity with valgus stress. The absence of pain with resisted wrist flexion, and the location of pain slightly posterior to the common flexor muscle origin can help differentiate UCL injury from flexor-pronator muscle injury (epicondylitis). It should be noted, however, that UCL injury and epicondylitis can occur simultaneously. Ecchymosis may develop in the medial joint line and proximal forearm 48 to 72 hours after an acute UCL injury. With a torn or attenuated UCL, valgus stress will result in medial joint opening, while the ulnar nerve is also stretched. Long-standing fixed flexion and valgus deformities, as frequently seen in older baseball pitchers and tennis players, are static deformities that may predispose the athlete to traction neuritis, as described above.[62,63]

Essential to diagnosing UCL injury is examination to determine the functional integrity of the ligament. There are many descriptions of how to best evaluate the ligament. Techniques to evaluate the UCL for laxity have classically been described with the humerus stabilized and a valgus force applied to the flexed (30°) elbow (Fig 4). In the athlete with an acute UCL rupture, care should be taken to test for flexor-pronator muscle avulsion as well. Norwood et al.[43] reported that the flexor-pronator muscle group was ruptured in all 4 of their patients with acute UCL tears, and Conway et al.[42] found a 13% incidence of flexor-pronator muscle rupture near its medial epicondylar origin. Athletes with the combined UCL and flexor-pronator muscle-tendon injury usually are tender at the medial epicondylar origin of the muscle, and have pain that is worsened with resisted wrist flexion. Com-

FIGURE 4. Valgus stress test of the elbow. Valgus stress applied to the elbow flexed 30°, palpating the UCL for tenderness and opening of the medial joint line. (Reprinted with permission.[65])

plete flexor-pronator musculotendinous rupture is associated with weakness of wrist flexion.

The "milking maneuver" is a test recently described for UCL injury. With this test, the athlete applies a valgus stress to the joint in flexion by themself.[64] With the milking maneuver, the affected elbow is flexed beyond 90° and the opposite hand of the patient is brought under the elbow being tested to grasp the thumb of the affected hand, applying a valgus stress to the affected elbow (Fig 5). The UCL is palpated by the examiner for tenderness and joint space opening during this test.[64,65] This technique of examination was proposed because more medial joint laxity is present when the elbow is tested at 90° of flexion compared with 30° of elbow flexion.[9] This test is performed comparing the injured elbow with the contralateral, normal, control elbow for laxity and quality of endpoint.

FIGURE 5. Milking maneuver. The patient's contralateral extremity helps lock the shoulder of the elbow being examined. While pulling down on the thumb of the elbow being examined, a valgus stress is imparted on the elbow and the examiner palpates the medial joint line of gapping. (Reprinted with permission.[65])

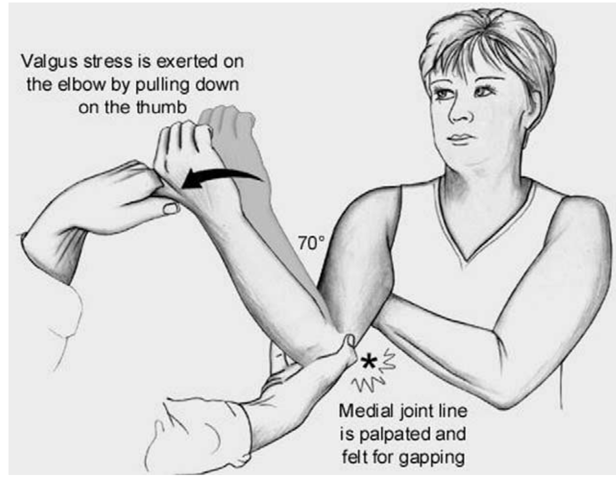

FIGURE 6. The author's modification of the milking maneuver. The patient still locks the shoulder of the upper extremity being examined by using the other arm. The examiner positions the patient's elbow at 70° and pulls on the subject's thumb imparting the valgus stress while palpating the medial joint line with the other hand. This author performs the examination in this fashion because biomechanical studies on cadavers suggest that 70° of elbow flexion is the best position to detect medial joint laxity to valgus stress. (Reprinted with permission.[94])

At least 1 investigator prefers a modification of the milking maneuver.[65] During the classically described milking maneuver, the patient's elbow is generally flexed greater than 120°. At this angle of elbow flexion, the contribution of the bony anatomy to elbow stability makes evaluation of the ligament less sensitive (Fig 6).[14] With the modified test, the athlete places the arm not being examined under the elbow being examined. This positions the shoulder of the elbow being examined in adduction and maximal external rotation, eliminating external rotation as a confounding motion, a problem with the classic tests for elbow valgus laxity. The subject's elbow is then held at 70° of flexion, the position of greatest valgus laxity when the UCL is sectioned in a cadaver model.[9,16,25] The examiner then uses 1 hand to pull down on the thumb of the elbow being examined, imparting a valgus stress to the elbow. At the same time, the examiner's other hand is used to palpate the medial joint

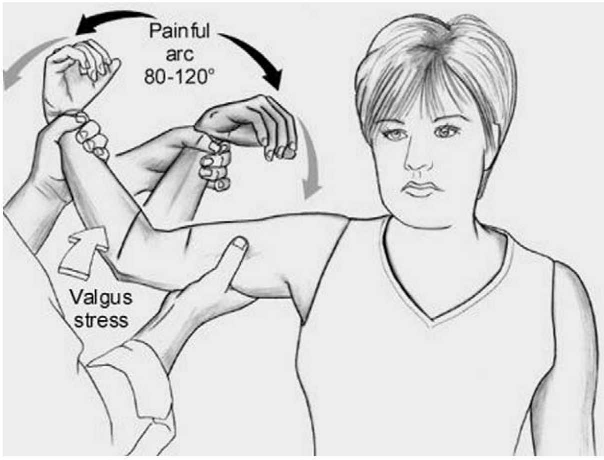

Figure 7. A recently described test for UCL injury was described by O'Driscoll (O'Driscoll SW, Lawton RL, Smith AM. The 'moving valgus stress test' for medial collateral ligament tears of the elbow. *Am J Sports Med* 2005;33:231-239.). The patient brings his shoulder into abduction and external rotation. The examiner flexes and extends the patient's elbow while applying a valgus force. In the patient with an UCL injury, this should reproducibly cause pain in the arc between 80° and 120°. (Reprinted with permission.[94])

line to feel for increased medial joint space and end-point feel.

The center of the varus–valgus axis is along the center of the trochlea, which is more medial than the midline. As a result, valgus stress testing of an elbow with an attenuated or torn UCL results in less medial joint opening or gapping than if the lateral ligamentous complex were injured. Medial joint space opening is usually only a few millimeters with complete, isolated UCL injuries. This subtle degree of laxity may explain why studies by experienced clinicians have noted the ability on physical examination to detect valgus elbow laxity preoperatively of 26% to 82%.[66,67]

Recent cadaveric studies have been performed to identify the humeral, elbow, and forearm position that best demonstrates valgus laxity in the UCL injured elbow. With the elbow at 30°, 70°, or 90° of flexion, forearm rotation in neutral was the best position to show valgus laxity, compared with maximal (90°) pronation and maximal (90°) supination.[68] Of note, there was no significant difference in valgus laxity comparing the different degrees of elbow flexion (30°, 70°, or 90°).[68] Further, there is no statistical difference in valgus laxity when valgus force is applied 10° in either direction from perpendicular to the joint, as assessed with humeral internal and external rotation.[69]

Recently, another test has been described to identify UCL insufficiency, the Mayo Valgus Stress Test, described by O'Driscoll and Lawton[70] (Fig 7). In this examination, the athlete's shoulder is placed in an abducted and externally rotated position. The elbow is then flexed and extended while imparting a valgus force to the elbow. For those athletes with UCL insufficiency, pain is felt at a specific and reproducible point within the arc of 80° to 120° of elbow flexion. This examination reproduces the pain of throwing in the athlete because the shearing force is applied to the attenuated UCL in a manner similar to throwing.

Other clinical clues studied to evaluate the UCL-deficient elbow include pain with valgus testing and tenderness of the UCL. Pain with valgus stress testing has been reported to be present in 26% to 53% of patients undergoing surgery for UCL insufficiency,[66,67] and UCL tenderness has been reported to be present in up to 80% of those undergoing UCL reconstruction.[67]

Imaging Studies

Multiple imaging modalities may be obtained that potentially can help confirm the diagnosis. Imaging modalities that have been shown to be of value include plain radiographs with or without valgus stress, arthrograms, computed tomography (CT) (with and without radiographic contrast), and magnetic resonance imaging (MRI) (with and without intra-articular contrast). Dynamic ultrasound has also been studied and reported to be of benefit in the evaluation of the UCL.

When a UCL bony avulsion exists, the small avulsion fracture fragment may be identified on plain radiographs. Plain radiographs can also be beneficial to identify findings suggestive of chronic UCL insufficiency. These secondary radiographic findings include ossification of the ligament (18%),[71] loose bodies in the posterior or lateral compartments, marginal osteophytes about the radiocapitellar or ulnohumeral articulations, and/or olecranon and condylar bony hypertrophy.

Instability can be confirmed using stress radiographs. In the case of an acute UCL injury, stress radiographs may be difficult because of patient guarding. Anesthetic may help relax the patient to allow for stress radiographs with an acute UCL injury. A commercially available stress device is available that applies valgus stress to the elbow at defined, reproducible forces and consistent elbow position. Published studies report this radiographic stress testing device to be 94% sensitive and 100% specific in diagnosing UCL tears.[72] However, it should be noted that increased valgus elbow laxity (nearly 0.5 mm) can occur in the uninjured, asymptomatic dominant elbow of professional baseball pitchers when compared with their nondominant elbow.[73] The side-to-side (dominant *v* nondominant) elbow valgus laxity difference in the general, nonthrowing, population has been shown to be less than 0.5 mm.[74,75] Because of the subtlety of this difference in normal elbows, asymptomatic elbows in throwing athletes, and injured elbows in symptomatic athletes, UCL injuries are often underestimated and misdiagnosed initially.[26] Conway[76] presented his findings of stress radiographic measurements in professional baseball pitchers and found that 2 mm of relative increased laxity and 3 mm of absolute medial joint opening were consistent with UCL insufficiency. Thompson et al.[67] published their findings in athletes undergoing UCL reconstruction, noting that 88% had greater than 2 mm of medial joint space opening compared with the contralateral, normal elbow, as measured in stress radiographs.[67] However, Azar et al.[66] reported that only 46% of their athletes who underwent UCL reconstruction had "positive" stress radiographs.[66]

The gravity stress test classically has been used to identify valgus laxity of the elbow.[49,77] The gravity stress test is performed with the patient supine and the shoulder of the elbow being filmed brought into maximal external rotation while the sagittal plane of the elbow is parallel to the floor. The forearm is left unsupported. The weight of the forearm is resisted by the flexor-pronator muscle group and the UCL only. A standard anteroposterior radiograph is taken of the elbow (parallel to the floor) and measured for medial joint opening. In the case of medial apophyseal injury (as classically described), if the apophysis translates distally and/or the joint gaps open medially, the elbow is defined as being unstable.[77]

An arthrogram may be useful, particularly to evaluate an acute injury. An arthrogram is of limited benefit in the case of chronic UCL insufficiency because the medial capsule is rarely ruptured with chronic UCL injury. Thus contrast leakage from the joint would not likely occur. A CT scan performed with intra-articular contrast has been shown to be 86% sensitive and 91% specific for acute and chronic injuries to the UCL in a study of 25 baseball players.[78] A purported advantage of the CT arthrogram is the ability to visualize a partial, undersurface tear of the UCL.[78,79] However, the role of CT arthrography must still be confirmed and further defined, particularly in reference to MRI, MR arthrogram, and dynamic ultrasound.

MRI has been shown to be helpful in identifying UCL injury.[78,80,81] MRI visualizes the ligament directly, including acute and chronic injury, and can reveal secondary structures that may be injured, including the insertion of the UCL or radiocapitellar overload by showing bony edema and chondral thinning. Timmerman et al.[78] found the MRI was 57% sensitive and 100% specific. However, Thompson et al.[67] found MRI to be positive in 79% of athletes undergoing UCL reconstruction, but "falsely" negative in 21%. The addition of intra-articular contrast to the MRI improves the ability to detect UCL injuries while maintaining the benefit of visualization of other bony and soft-tissue elbow structures. Azar et al.[66] reported that MRI arthrography was 97% sensitive in detecting UCL injury, including partial undersurface UCL tears.

Dynamic ultrasonography has recently been studied in asymptomatic major league professional baseball players for evaluating the UCL of the elbow.[82,83] Dynamic ultrasound provides a rapid means of evaluating the UCL. In these baseball players, dominant UCL had a thicker anterior band, and the UCL was more likely to have hypoechoic foci and/or calcifications. Further, dynamic ultrasound showed increased medial elbow laxity with valgus stress.[82,83]

The Role of Arthroscopy in Diagnosis

The efficacy of arthroscopy to confirm the diagnosis of UCL injury has been studied. Only 20% of the anterior oblique ligament and up to 50% of the posterior oblique ligament can be directly visualized using the arthroscope.[78,84] Timmerman et al.[78] have reported that arthroscopy is the most sensitive and specific way to diagnose UCL tears.[78] Because not much of the ligament itself can be directly visualized, the benefit of arthroscopy is that the medial compartment of the elbow can be visualized. When applying valgus stress to the elbow while it is flexed at 70° of elbow flexion, any medial compartment opening, that is the ulna moves away from the distal humerus, UCL insufficiency exists.[78] Field and Altchek[84] systematically studied the value of arthroscopy in the assessment of UCL injury in a cadaver model. They found testing the elbow to valgus stress in 70° of flexion was the best way to examine the elbow for UCL injury. They found that cutting of the anterior oblique ligament alone resulted in only 1 to 2 mm of medial joint space gapping to valgus stress, whereas complete sectioning of the UCL resulted in 4- to 10-mm distance between the distal humerus and ulna.[84] Field and

Altchek concluded that imaging studies may help confirm the diagnosis, but that the history and physical examination remain the mainstay for diagnosis.[84]

TREATMENT OF THE THROWER'S ELBOW

Treatment of UCL Rupture

Initial management of UCL injury consists of rest, anti-inflammatory measures, and physical therapy. With this conservative program, Barnes and Tullos[62] reported that half of their throwing athletes with UCL insufficiency were able to return to throwing and the other half required surgery.[62] In a larger series, Rettig et al.[85] reported the results of nonoperative treatment of 31 throwing athletes with UCL injuries. Nearly two thirds of the patients in their series were baseball pitchers and 42% of these athletes were able to return to their previous level of competition at an average 24.5 weeks (range, 13 to 54 weeks) of conservative management.[85] Jobe et al.[86] recommend treating athletic patients with a conservative program involving 2 cycles of 3 months of rest from throwing and rehabilitation. Conway et al.[42] recommend surgery if pain recurs when throwing over 75% capacity despite the 6 months of conservative treatment. The percentage of their athletes who have successfully returned to sports with this nonoperative program has not been published. The nonoperative program of Rettig et al.[85] consists of 2 or more months of rest from throwing, upper extremity strengthening, and bracing; they initiate a throwing program when the athlete is free of pain, which is advanced over 1 to 2 months.

Surgical treatment for UCL tears has evolved over the time. Early surgical management of UCL insufficiency consisted of transferring the anterior oblique ligament anteriorly and superiorly when the UCL was present but attenuated.[24] This treatment has generally fallen out of favor and been abandoned because the remaining attenuated ligament is believed to be weaker as the result of the repeated microtrauma, its transferred position is not functionally isometric, and a flexion contracture usually results because of the position of the transfer, which may not be acceptable in the high-level athlete.

Primary repair of the ligament for acute injuries had been advocated for many years.[42,62,77] Most ligamentous avulsions have traditionally been treated by reattaching the ligament to bone through drill holes while midsubstance ruptures were repaired primarily.[43] Conway et al.[42] reported the relative prevalence of UCL injury by location in 70 athletes with acute UCL injuries: 87% of the injuries were midsubstance, 10% were avulsions from the ulna, and only 3% were avulsions from the humerus.[42] They noted that 71% of those treated with primary UCL repair reported good to excellent results, but that only 7 of the 14 athletes treated with primary repair were able to return to their same level of throwing.[42] The ability to return to sports at the same level as before injury was reported by Conway et al. to be better with UCL reconstruction with use of a free graft compared with primary repair.[42] Conway et al.[42] and Jobe et al.[86] recommended UCL reconstruction with a free tendon graft in the acute setting as their treatment of choice with 1 exception. Conway et al. recommended primary repair for the few patients who have surgery soon after an acute humeral avulsion of the UCL, with no ulnar nerve symptoms, and with the remainder of the ligament appearing normal.[42,86] Azar et al.[66] also found better results with UCL reconstruction (81% able to return to play at the same or higher level) compared with primary UCL repair (63% return to play at the same or higher level). Because of the relatively consistently good results with reconstruction as reported by Jobe and others, most surgeons now prefer to perform UCL reconstruction for acute and chronic injuries.[65,66]

UCL reconstruction involves using a graft to anatomically reconstruct the UCL. Grafts used include ipsilateral or contralateral palmaris longus, fourth toe extensor, hamstring tendon, strip of Achilles tendon, plantaris tendon, and allograft (hamstring and posterior or anterior tibialis tendon). UCL reconstruction is fixed to bone through tunnel(s) in the ulna at the sublime tubercle and in the humeral epicondyle. This is discussed in more detail below. Ulnar nerve transposition may be performed in conjunction with UCL reconstruction, although because of a significant risk of neurologic problems with the ulnar nerve postoperatively (up to 21%), this is done more sparingly.[42,66]

Indications for UCL reconstruction include (1) acute ruptures in high-level throwers, (2) significant chronic instability, (3) after debridement for calcification within the UCL and there is insufficient tissue to effect a primary repair in a throwing athlete, and (4) multiple episodes of recurring pain (with subtle instability) with throwing after 2 cycles of a supervised rehabilitation program.

Frank W. Jobe developed the original UCL reconstruction and described the technique with initial results in 1986.[86] The technique used a tendinous transection and reflection of the flexor-pronator mass,

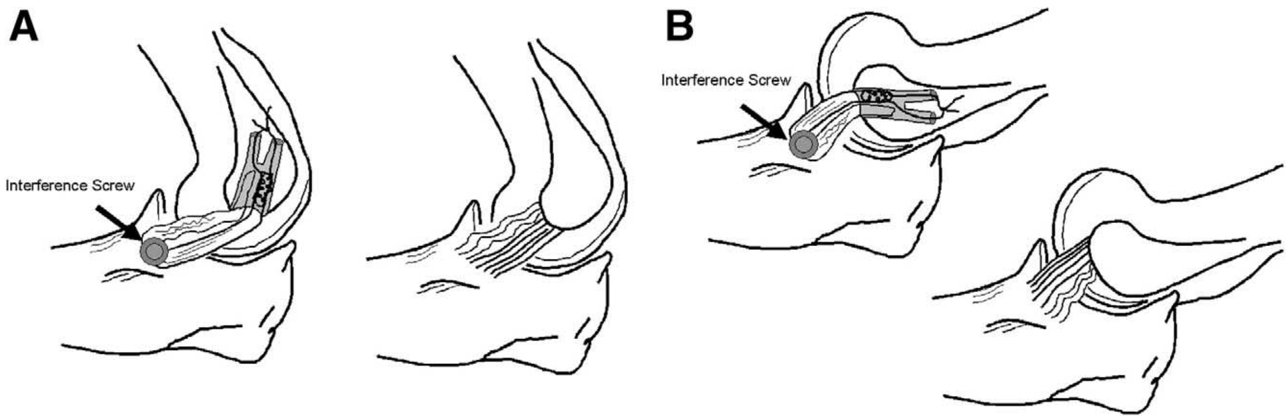

FIGURE 8. Hybrid technique of UCL reconstruction described by one of the authors (N.S.E.). This technique of UCL reconstruction combines a single tunnel at the ulnar insertion fixed with an interference screw with the docking procedure, and a single blind-ended tunnel in the humeral epicondyle. The modification proximally is that 1 suture from each graft limb is passed through the anterior tunnel and the 2 remaining sutures are passed through the posterior tunnel. (A) After the graft is pretensioned, the elbow is positioned at 80° of flexion and varus stress applied and the posterior band sutures tied. This replicates the anatomy of the posterior band of the anterior oblique ligament and is tight where the posterior band functions. (B) Then with the elbow positioned at 30° of flexion, varus stress is applied, and the anterior band sutures are tied independently. This replicates the anatomy of the anterior band and is tightened in the range the anterior band is most taut. This allows the graft to be selectively tensioned and, ideally, to more closely reproduce the functional anatomy of the anterior oblique ligament with posterior and anterior bands.

submuscular transposition of the ulnar nerve, and creation of humeral tunnels that penetrated the posterior cortex. This technique offered excellent exposure at the expense of morbidity to the flexor-pronator mass and ulnar nerve. Because of the importance of the flexor carpi ulnaris and flexor digitorum in dynamically stabilizing the elbow,[32] modifications in the surgical technique have been made to ease technical demands and decrease soft-tissue morbidity. A muscle-splitting approach has been developed to avoid detachment of the flexor-pronator mass with or without subcutaneous transposition of the ulnar nerve.[67,87] Another alternative to transecting the flexor-pronator mass that has been used with good success is elevating the flexor-pronator tendon without detaching or splitting it.[26,66]

Modifications in bone tunnel creation have also been made that direct the tunnels anterior on the humeral epicondyle to avoid risk of ulnar nerve injury while the graft remains passed in a figure-of-8 fashion.[67] Further changes in bone tunnel configuration have also been developed to reduce the number of tunnels and facilitate easier graft tensioning.[88,89] Other revisions in technique have been advocated to reduce complications. Initially, reports on UCL reconstruction recommended ulnar nerve transposition, but currently they recommend not transferring the ulnar nerve to reduce the significant complication rate of 21% associated with ulnar nerve transposition in conjunction with ligament reconstruction.[67,87] To facilitate easier graft tensioning and decrease the number of bone tunnels required, Rohrbaugh et al.[88] reported using a blind-ended tunnel on the humeral side (the docking technique) with excellent success, which has been confirmed by Paletta and Wright.[90]

A new technique of UCL reconstruction has been evaluated in the laboratory that reconstructs the central isometric fibers of the native ligament and achieves fixation in single bone tunnels in the ulna and humeral epicondyle using interference screw fixation.[89] This technique is less technically demanding because the required number of drill holes necessary is reduced from 5 to 2. Less dissection through a muscle-splitting approach is afforded because only a single central tunnel is required rather than 2 tunnels with an intervening bony bridge on the ulna. With a single tunnel, the posterior ulnar tunnel, which is nearest to the ulnar nerve, is avoided. Finally, graft passage and tensioning is less difficult with interference screws in a single tunnel. While the biomechanics of this technique are encouraging, clinical outcome results of this technique are presently not available.

Recently, one of the authors (N.S.E.) has developed a technique that allows reconstruction and independent tensioning of the anterior and posterior bands of the anterior oblique ligament of the UCL that are not accomplished with the other described techniques. This technique is a hybrid of the interference screw technique distally (in the ulna) and docking procedure proximally (in the humeral epicondyle) (Fig 8).

There has also been a report published on the biomechanical results of UCL reconstruction with suture anchors to provide graft fixation onto bone as compared with tunnels.[91] The clinical outcomes of this technique have yet to be published. There have been recent discussions on the use of allograft for UCL reconstruction, but there have been no reports on the results of this technique. Synthetic ligament research is an area of interest as well, but it is too early to know if this will be successful.

Reports of these technique modifications register complication rates of 10% or less, suggesting these modifications are useful in reducing the rate of complications associated with UCL reconstruction.[66,67,90,92] Unfortunately, there have been no studies directly comparing reconstruction techniques to help identify the best technique.

Postoperatively, the elbow is immobilized in a splint for 10 days to allow the skin and soft tissues to heal. Then active wrist, elbow, and shoulder range of motion exercises are initiated. A hinged brace allowing for range of motion, or no brace, is used after surgery. After 4 to 6 weeks, strengthening exercises are begun, avoiding valgus stress until postoperative weeks 14 to 16, at which time the patient begins a throwing program. Initially, the athlete begins with ball toss of 30 to 40 feet, 2 to 3 times a week for about 15 minutes. At 5 months, the patient may increase the tossing distance to 60 feet, and at 6 months the patient may perform throwing lightly from the wind-up. At 7 months, a graduated program of range of motion, strengthening, and total-body conditioning exercises is begun. Throwers and pitchers are limited to throwing at half speed, while gradually increasing the duration of their session to 25 to 30 minutes. Pitchers are permitted to throw from the pitching mound and progress to 70% of maximum velocity during the eighth or ninth month. Over the next 2 to 3 months, the duration of throwing sessions and velocity are slowly increased to simulate a game situation. Throwing in competition is permitted at 1 year if the shoulder, elbow, and forearm are pain free while throwing and full strength and range of motion have returned. Throughout the rehabilitation phase, careful supervision and focus on body and throwing mechanics should be emphasized. In a professional pitcher, it may require more than 18 months to regain preoperative ability and competitive level, with relatively shorter periods required for other player positions or overhead sports.[67]

Conway et al.[42] reported their results of 56 UCL reconstructions using a palmaris longus free tendon graft. At 2 to 5 years follow-up, they reported 80% good-to-excellent results with 68% of the athletes returning to their previous level of competition for more than 1 year.[42] They noted in their series a postoperative ulnar neuropathy rate of 21%, with 40% being transient (all but 1 patient returned to his previous sports activity). However, 60% of those with an ulnar neuropathy required a second surgical procedure for the nerve (almost half returned to previous sports activity).[42] The results of reconstruction of the UCL were not as good when there had been a previous operative procedure performed on the elbow. Other more recent reviews report that 79% to 97% of athletes are able to return to their sport following UCL reconstruction, although most of these had reconstruction without detachment of the flexor-pronator muscles.[26,49,66,67,88,90,92]

Treatment of Loose Bodies

For patients with symptomatic loose bodies, the obvious treatment is to remove them. Loose body removal is usually performed arthroscopically because of its minimal morbidity when compared with arthrotomy. It should be noted that loose bodies are likely to recur if the athlete continues to participate in the sport that produced the valgus forces initially, especially when concomitant valgus laxity persists. Most studies have found that athletes (including professional baseball pitchers) are able to return to their previous level of activity after removal of the loose bodies. Bennett and Tullos[77] reported their experience with open removal of loose bodies; they found that the average professional baseball pitcher continued to throw effectively 3 years after their arthrotomy (range, 2 to 11 years). However, they also remarked that the loose bodies will recur in those athletes who return to throwing because pitching is inherently a process destructive to the elbow.[77] Recent publications confirm the usefulness of arthroscopic loose body removal with its low morbidity and possibly quicker return to activity, especially when there is no associated degenerative joint disease.[93]

Treatment of Valgus Extension Overload

As noted above, athletes who present with valgus extension overload should also be thoroughly evaluated and considered for UCL reconstruction. Of professional baseball players who underwent olecranon debridement, 42% had further surgery, including 25%

who developed valgus instability and eventually required UCL reconstruction.[26] It is not entirely clear if this significant UCL reconstruction rate indicates that the olecranon contributes to valgus stability and olecranon resection increases the demand placed on the UCL, or that by removing part of the olecranon, subtle UCL laxity is unmasked.

Initial treatment of valgus extension overload without loose bodies consists of relative rest, anti-inflammatory measures, and strengthening of the flexor-pronator muscles. It has been the authors' experience that if posteromedial osteophytes exist on the olecranon, nonoperative management is not often successful. Nonetheless, if an athlete fails 6 to 12 weeks of conservative management, surgical excision is indicated.

Based on clinical and basic science studies, we advocate careful evaluation of the UCL in patients presenting with valgus extension overload. We believe that consideration should be given to UCL reconstruction in combination with posterior debridement in these patients who fail nonoperative treatment and have combined posteromedial impingement and UCL injury. Furthermore, based on these studies, we believe that posterior debridement should be limited only to removal of the osteophytes, leaving the normal olecranon intact.

CONCLUSIONS AND SUMMARY

The elbow is a complex joint that allows for the transmission of forces from the lower extremity to the ball, racket, or other instrument. In many sports, it must withstand tremendous forces, particularly valgus forces, that are not often encountered in regular activities of daily living. Significant valgus torque can be destructive, with medial elbow tensile forces, lateral compressive forces, and posterior shear forces. The UCL is commonly injured in throwing sports, but it may not always be manifest by gross valgus laxity or pain at the ligament. The athlete with UCL injury may present with symptoms related to secondary overload of other areas about the elbow accentuated by UCL laxity, such as medial epicondylitis, ulnar neuritis, lateral elbow pain caused by radiocapitellar overload, and posterior elbow pain from valgus extension overload or loose bodies. The clinician must maintain a high index of suspicion for any pain about the elbow in the throwing athlete as being potentially attributable to UCL insufficiency. It is important to direct management at the underlying problem, not just the symptom, because treating the symptom rarely prevents the symptoms from returning.

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