Medial Elbow Problems in the Overhead-Throwing Athlete

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Abstract

The elbow is subjected to enormous valgus stresses during the throwing motion, which places the overhead-throwing athlete at considerable risk for injury. Injuries involving the structures of the medial elbow occur in distinct patterns. Although acute injuries of the medial elbow can occur, the majority are overuse injuries as a result of the repetitive forces imparted to the elbow by throwing. Injury to the ulnar collateral ligament complex results in valgus instability. Valgus extension overload leads to diffuse osseous changes within the elbow joint and secondary posteromedial impingement. Overuse of the flexor-pronator musculature may result in medial epicondylitis and occasional muscle tears and ruptures. Ulnar neuropathy is a common finding that may be due to a variety of factors, including traction, friction, and compression of the ulnar nerve. Advances in nonoperative and operative treatment regimens specific to each injury pattern have resulted in the restoration of elbow function and the successful return of most injured overhead athletes to competitive activities. With further insight into the relevant anatomy, biomechanics, and pathophysiology involved in overhead activities and their associated injuries, significant contributions can continue to be made toward prevention and treatment of these injuries.

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The elbow is subjected to tremendous valgus stresses during overhead activities, which result in specific injury patterns unique to the throwing athlete. The forces generated as the result of repetitive throwing are primarily concentrated on the medial structures of the elbow. Consequently, medial elbow problems predominate in the athlete engaged in overhead activities. Although acute traumatic injuries to the osseous, musculotendinous, and ligamentous structures of the elbow may occur, the majority are chronic overuse injuries resulting from repetitive intrinsic and extrinsic overload. Baseball players are the athletes most commonly affected; medial elbow symptoms account for up to 97% of elbow complaints in pitchers. However, athletes who participate in other sports that require similar overhead motion, such as football, volleyball, tennis, and javelin throwing, can be likewise affected. A thorough understanding of functional elbow anatomy and the biomechanics of throwing is essential to the recognition, diagnosis, and treatment of these specific elbow injuries.

Functional Anatomy of the Medial Elbow

The osseous anatomy of the elbow allows flexion-extension and pronation-supination through the ulnohumeral and radiocapitellar articulations, respectively. In full extension, the elbow has a normal valgus carrying angle of 11 to 16 degrees. The osseous configuration provides approximately 50% of the overall stability of the elbow, primarily against varus stress with the elbow in extension. The remaining stability of the elbow is provided by the anterior joint capsule, the ulnar collateral ligament (UCL) complex, and the radial collateral ligament complex.[1-3]

The UCL complex is composed of three main portions: the anterior bundle, the posterior bundle, and the oblique bundle (transverse ligament) (Fig. 1). The anterior bundle, consisting of parallel fibers inserting onto the medial coronoid pro-

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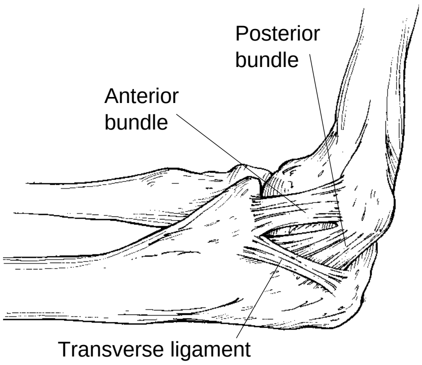


Figure 1 The UCL complex consists of the anterior bundle (functionally the most important for valgus stability), the posterior bundle, and the transverse ligament (oblique bundle). The anterior bundle is further subdivided into anterior and posterior bands, which perform reciprocal functions. (Adapted with permission from Kvitne RS, Jobe FW: Ligamentous and posterior compartment injuries, in Jobe FW [ed]: *Techniques in Upper Extremity Sports Injuries*. Philadelphia: Mosby-Year Book, 1996, p 412.)

cess, is functionally the most important in providing stability against valgus stress.[1,2,4] Its origin is the inferior aspect of the medial epicondyle of the humerus. The anterior bundle is eccentrically located with respect to the axis of elbow motion, enabling it to provide stability throughout the full range of motion.[3] The anterior bundle is further subdivided into distinct anterior and posterior bands, which perform reciprocal functions.[2,5,6] The anterior band is the primary restraint to valgus stress up to 90 degrees of flexion, and becomes a secondary restraint with further flexion.[6] The posterior band is a secondary restraint at lesser degrees of flexion, but becomes functionally more important between 60 degrees and full flexion.[5,6] Sequential tightening occurs within the fibers of the anterior bundle, progressing from anterior to posterior as the elbow flexes.[5] The posterior band is nearly isometric and is functionally more important in the overhead athlete, as it is the primary restraint to valgus stress with higher degrees of flexion (N. ElAttrache, MD, F.W.J., J.G. Rosen, unpublished data). The anterior band is more vulnerable to valgus stress with the elbow extended, whereas the posterior band is more vulnerable with the elbow flexed.[2,3,5,6]

The fan-shaped posterior bundle of the UCL complex originates from the medial epicondyle and inserts onto the medial margin of the semilunar notch. It is thinner and weaker than the anterior bundle and provides secondary elbow stability at flexion beyond 90 degrees.[1,2,5] The posterior bundle has been shown to be vulnerable to valgus stress only if the anterior bundle is completely disrupted.[6]

The oblique bundle, or transverse ligament, does not cross the elbow joint. Rather, it serves to expand the greater sigmoid notch as a thickening of the caudalmost aspect of the joint capsule extending from the medial olecranon to the inferior medial coronoid process.[3]

The musculotendinous anatomy of the elbow originating from the medial epicondyle includes the flexor-pronator musculature and provides dynamic functional resistance to valgus stress.[7] From proximal to distal, this muscle mass includes the pronator teres, flexor carpi radialis (FCR), palmaris longus, flexor digitorum superficialis, and flexor carpi ulnaris (FCU). The pronator teres and FCR arise from the medial supracondylar ridge. The palmaris longus originates from the anterior midportion of the medial epicondyle. The FCU arises from the anterior base of the epicondyle and possesses both humeral and ulnar heads.

The ulnar nerve is commonly susceptible to injury during overhead athletic activities (Fig. 2). Proximally, the ulnar nerve passes through the arcade of Struthers, which is located approximately 8

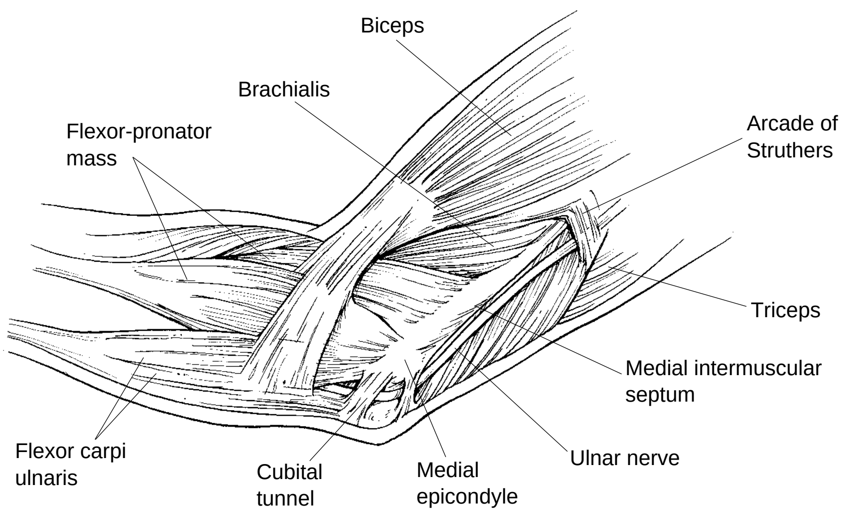


Figure 2 The ulnar nerve courses around the medial aspect of the elbow. Proximally, the nerve passes beneath the arcade of Struthers, runs along the medial intermuscular septum, enters the cubital tunnel around the medial epicondyle, and passes through the two heads of the FCU. (Adapted with permission from Boatright JR, D'Alessandro DF: Nerve entrapment syndromes at the elbow, in Jobe FW, Pink MM, Glousman RE, Kvitne RE, Zemel NP [eds]: *Operative Techniques in Upper Extremity Sports Injuries*. St Louis: Mosby-Year Book, 1996, p 520.)

cm proximal to the medial epicondyle. The arcade, running obliquely and superficial to the ulnar nerve, is composed of the deep investing fascia of the arm, the superficial fibers of the medial head of the triceps, and an expansion of the coracobrachialis tendon. The ulnar nerve then traverses the medial intermuscular septum at the midpoint of the arm as it passes from the anterior to the posterior compartment. An anastomotic arterial network consisting of branches of the superior and inferior ulnar collateral arteries proximally and the posterior ulnar collateral artery distally accompanies the nerve as it enters the cubital tunnel.

The floor of the cubital tunnel is formed by the UCL, whereas the roof is formed by the overlying arcuate, or Osborne, ligament. The medial head of the triceps constitutes the posterior border of the tunnel; the anterior and lateral borders are formed by the medial epicondyle and the olecranon, respectively.

After traversing the cubital tunnel, the ulnar nerve enters the forearm by passing between the two heads of the FCU, eventually resting on the flexor digitorum profundus. The sensory fibers within the ulnar nerve are located more peripheral and anteromedial than the motor fibers and are therefore more susceptible to injury.[8]

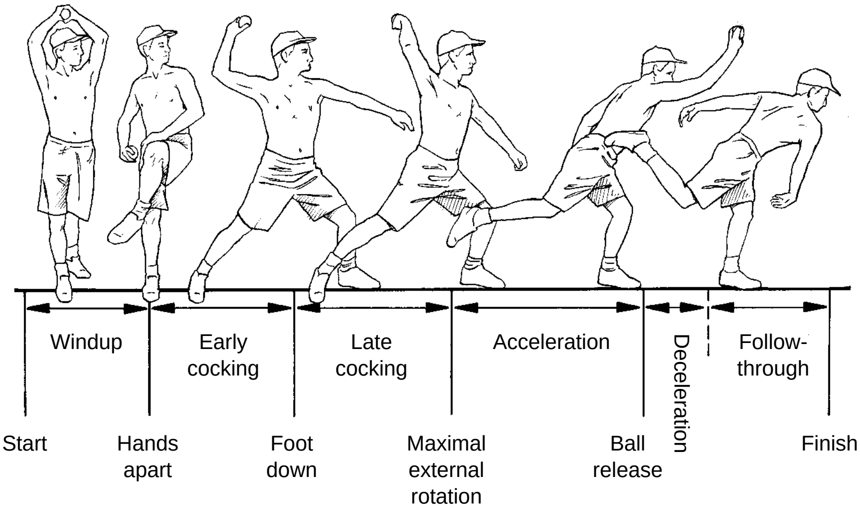


Figure 3 The five main stages of the overhead throwing motion. (Adapted with permission from DiGiovine NM, Jobe FW, Pink M, Perry J: An electromyographic analysis of the upper extremity in pitching. *J Shoulder Elbow Surg* 1992;1:15-25.)

Biomechanics of Throwing

Although specific techniques of overhead throwing vary with different sports, the overall basic throwing motion is similar. The baseball pitch has been the most studied and can be divided into five main stages (Fig. 3).[3,9-13] Stage I, or windup, involves initial preparation as the elbow is flexed and the forearm is slightly pronated. Stage II, or early cocking, begins when the ball leaves the nondominant gloved hand and ends when the forward foot comes in contact with the ground. The shoulder begins to abduct and externally rotate. Stage III, or late cocking, is characterized by further shoulder abduction and maximal external rotation, as well as elbow flexion between 90 and 120 degrees and increasing forearm pronation to 90 degrees.

Rapid acceleration of the upper extremity, or stage IV, follows and is marked by the generation of a large forward-directed force on the extremity by the shoulder musculature, resulting in internal rotation and adduction of the humerus coupled with rapid elbow extension. Stage IV terminates with ball release and occurs over a period of only 40 to 50 msec, during which the elbow accelerates as much as 600,000 degrees/sec^2.[14] Tremendous valgus stresses are generated about the medial aspect of the elbow. The anterior bundle of the UCL complex bears the principal portion of these forces; the secondary supporting structures (e.g., the flexor-pronator musculature) facilitate transmission of these forces.[7,11] Most elbow injuries occur during stage IV (acceleration) as a result of the concentration of stresses and loads on the medial elbow structures.

Stage V, or follow-through, involves dissipation of all excess kinetic energy as the elbow reaches full extension and ends when all motion is complete. Rapid and forceful deceleration of the upper extremity occurs at a rate of almost 500,000 degrees/sec^2 over a time span of 50 msec.[3,9-14] Throwing curveballs, which theoretically requires elbow deceleration over a shorter time interval and potentially results in greater elbow angular velocities, has not been clinically shown to have greater adverse effects on the elbow.[13,15]

Valgus Instability

Injury to the UCL, initially recognized in javelin throwers, has been reported to occur with increasing frequency in other types of overhead athletes as well. Microtears of the UCL occur once the valgus forces generated during the cocking and acceleration phases of throwing exceed the intrinsic tensile strength of the UCL. Improper throwing mechanics, poor flexibility, and inadequate conditioning result in additional cumulative stress transmission to the UCL complex, leading to attenuation and eventual rupture of the UCL.[3,15]

Evaluation

The diagnosis of valgus instability is based on the athlete's history, physical examination, and radiographic studies. Patients with acute UCL injury usually experience the sudden onset of pain after throwing—with or without an associated popping sensation—and are unable to continue throwing. Patients with chronic injury usually describe a gradual onset of localized medial elbow pain during the late-cocking or acceleration phase of throwing. Athletes may also describe pain after an episode of heavy throwing that results in the inability to subsequently throw at more than 50% to 75% of their normal level. Patients with chronic instability also commonly present with ulnar nerve symptoms. This is due to local inflammation of the ligamentous complex, which produces secondary irritation of the ulnar nerve within the cubital tunnel.[3]

Physical examination of the elbow for valgus instability is best performed with the patient seated and the wrist secured between the examiner's forearm and trunk (Fig. 4, A). The patient's elbow is flexed between 20 and 30 degrees to unlock the olecranon from its fossa as a valgus stress is applied.[8] This maneuver stresses the anterior band of the anterior bundle of the UCL.[3,8,16] It is important to palpate the UCL along its course from the medial epicondyle toward the proximal ulna as valgus stress testing is performed. Valgus laxity is manifested by increased medial joint-space opening as compared to the contralateral extremity. Comparison with the uninvolved elbow should always be performed to differentiate between physiologic and pathologic laxity. Loss of a firm endpoint coupled with increased medial joint-space opening with valgus stress is consistent with an attenuated or incompetent UCL.

Testing of the functionally more important posterior band of the anterior bundle can be accomplished by the milking maneuver, which is performed by pulling on the patient's thumb with the patient's forearm supinated, shoulder extended, and elbow flexed beyond 90 degrees (Fig. 4, B).[3] This maneuver generates a valgus stress on the flexed elbow; a subjective feeling of apprehension and instability, in addition to localized medial-side elbow pain, is indicative of UCL injury.

Point tenderness and swelling over the UCL vary with the amount of inflammation and edema present. The absence of increased pain with wrist flexion, combined with pain localization slightly posterior to the common flexor origin, differentiates UCL injury from flexor-pronator muscle injury.[3,15,16] Decreased range of motion (loss of terminal extension) secondary to flexion contractures (which develop as a result of the repeated attempts at healing and stabilization) may also be present in cases of chronic valgus instability.[8] Overall performance by the athlete, however, may not be significantly compromised, as the throwing motion does not require full elbow extension and can be accomplished with a flexion arc between 20 and 120 degrees.[16]

Routine radiographs may show changes consistent with chronic instability, such as calcification and occasionally ossification of the ligament. Stress radiographs can be used to confirm instability, especially in apprehensive patients and in patients in whom the clinical findings are equivocal (Fig. 5). Medial joint opening greater than 3 mm is consistent with instability.[2,3]

Magnetic resonance (MR) imaging is useful in evaluating ligamentous avulsions, partial ligamentous injuries, midsubstance tears, and the status of the surrounding soft tissues.[3,17] Computed tomographic arthrography has also been reported to be useful in the evaluation of the UCL complex.

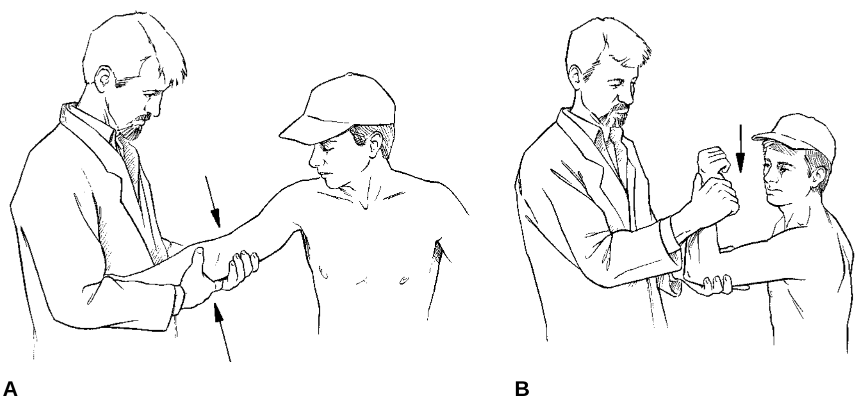


Figure 4 **A,** Examination of the anterior band of the anterior bundle of the UCL complex is performed with the patient sitting and the elbow slightly flexed as a valgus stress is applied to the elbow. **B,** The milking maneuver, performed with the patient's elbow flexed beyond 90 degrees while applying a valgus stress, tests the posterior band of the anterior bundle of the UCL complex. (Adapted with permission from Kvitne RS, Jobe FW: Ligamentous and posterior compartment injuries, in Jobe FW [ed]: *Techniques in Upper Extremity Sports Injuries*. Philadelphia: Mosby-Year Book, 1996, p 415.)

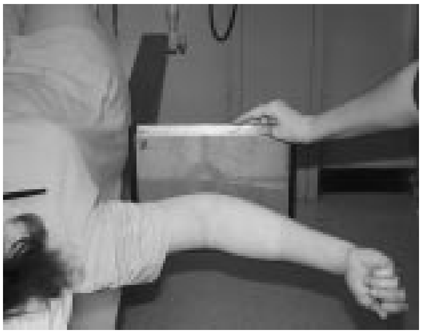


Figure 5 Gravity valgus stress radiographs—taken with the patient supine and the unsuspended, externally rotated arm held out at the side to allow the weight of the forearm to deliver a valgus stress to the elbow—are a helpful adjunct in the diagnosis of valgus instability. (Reproduced with permission from Miller CD, Savoie FH III: Valgus extension injuries of the elbow in the throwing athlete. *J Am Acad Orthop Surg* 1994;2:261-269.)

Treatment

Specific treatment programs may be implemented after the diagnosis of valgus instability is made. Initially, a nonoperative treatment protocol is instituted to reduce inflammation and pain. A brief period of rest (2 to 4 weeks) is recommended, coupled with use of nonsteroidal anti-inflammatory medications (NSAIDs) and local physical therapy modalities. Corticosteroid injections are not recommended, as further ligamentous attenuation may occur.

Once the acute inflammation has subsided, a supervised flexibility and strengthening program is instituted, aimed at restoring muscle tone, strength, and endurance to provide dynamic elbow stability. The pronator teres, FCU, and flexor digitorum superficialis should be targeted, as they are potentially important secondary dynamic stabilizers of the elbow.[7,9,11,13] Electromyographic analysis has shown maximal activity of the flexor-pronator mass during the acceleration phase of the pitching cycle in healthy athletes; however, in athletes with valgus instability, a paradoxical decrease in activity has been observed in these muscle groups.[10,11] This finding may be a reflection of the primary disorder predisposing the elbow to instability, or may be attributable to muscular inhibition through a painful feedback loop arising from injury to the UCL complex.[10,11] This situation is similar to that observed in overhead athletes with anterior shoulder instability in which the subscapularis (a dynamic stabilizer of the shoulder) has been shown to have decreased activity.[10] Strengthening and conditioning of the flexor-pronator mass may potentially enhance performance by increasing valgus stabilization and theoretically increasing functional protection of the UCL.[7,10]

A well-supervised throwing and conditioning program is begun at 3 months, once the athlete has regained full range of motion and strength. In addition, an evaluation of the athlete's throwing motion is essential to identify and correct improper mechanics. Nonoperative management instituted at an early stage has been shown to arrest the progression of instability and functional impairment, with as many as 50% of athletes being able to return to their preinjury level of throwing.

Surgical intervention is indicated for competitive athletes with acute complete ruptures of the UCL or chronic symptoms secondary to instability that have not significantly improved after at least 3 to 6 months of nonoperative management. Operative treatment consists of either repair or reconstruction of the UCL. The goals of surgery are to reestablish stability of the elbow and to allow the athlete to return to maximal functional levels.[3]

Direct repair of the UCL is reserved for acute ligamentous avulsions from the humeral origin or the coronoid insertion.[15,16,18] More commonly, however, chronic repetitive microtrauma leads to attenuation and midsubstance tears of the ligament. The UCL is significantly scarred and tenuous, precluding an effective primary repair. In these cases, graft reconstruction of the ligament is necessary. Options for autologous grafts include the ipsilateral or contralateral palmaris longus tendon, the plantaris tendon, a 3.5-mm medial strip of the Achilles tendon, or a portion of the hamstring tendons.[3,15,16] Allografts may also be utilized.

Surgical reconstruction begins with an approach centered over the medial epicondyle. Care must be taken to preserve the medial antebrachial cutaneous nerve. Next, while preserving the flexor-pronator origin on the medial epicondyle, the common flexor mass is split longitudinally in line with its fibers in its posterior third near the FCU and subsequently separated from the underlying ligamentous-capsular complex. The ligament is next inspected as a valgus stress is applied. The ligamentous-capsular complex is then incised to allow access into the elbow joint. Any osteophytes, loose bodies, and calcifications should be removed. Posterior compartment involvement, if present in cases of chronic instability, may be addressed through a separate posteromedial arthrotomy posterior to the ulnar nerve.[8,16] Loose bodies in the posterior compartment, as well as osteophytes on the posteromedial olecranon margin, may be removed through this approach.

Next, the anatomic origin and insertion of the anterior bundle of the UCL are identified. Osseous tunnels are then made in the proximal ulna at the level of the coronoid tubercle and in the medial epicondyle at the level of the anatomic UCL origin (Fig. 6, A). A single entrance hole is made in the medial epicondyle, with two divergent exit holes anterosuperiorly. The drill holes must be placed precisely at the anatomic origin and insertion sites of the native UCL to maintain

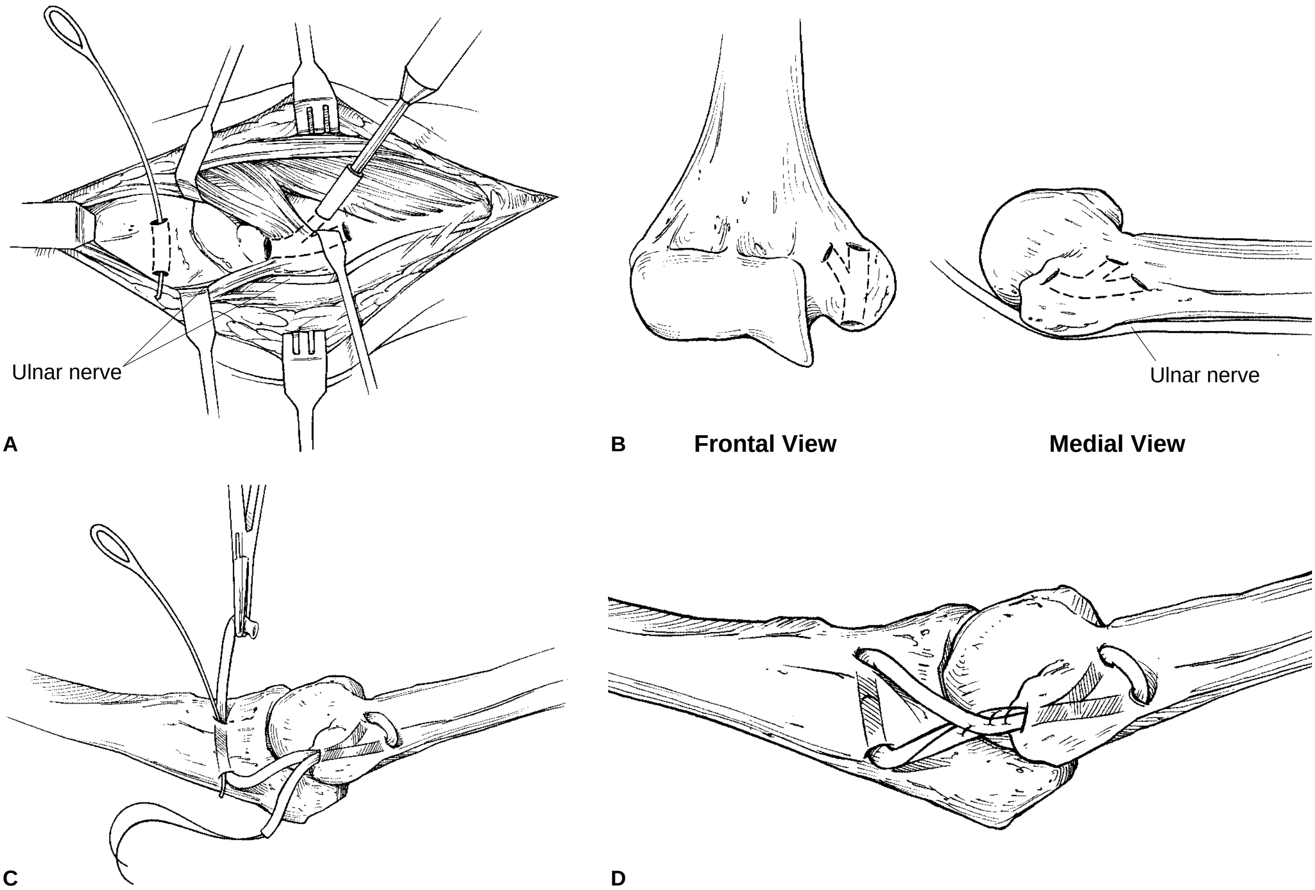


Figure 6 **A,** Transosseous drill holes through the medial epicondyle and olecranon are made for preparation of graft passage. Care is taken to avoid penetration of the posterior cortex of the medial epicondyle to prevent injury to the ulnar nerve within the cubital tunnel. **B,** Divergent exit tunnels are placed within the medial epicondyle near the anatomic origin of the anterior bundle of the UCL. **C,** The autologous graft is passed in a figure-of-eight fashion through transosseous drill holes in the medial epicondyle and olecranon. **D,** The graft is subsequently tensioned and sutured to itself in 45 degrees of flexion and neutral varus-valgus alignment. (Adapted with permission from Kvitne RS, Jobe FW: Ligamentous and posterior compartment injuries, in Jobe FW [ed]: *Techniques in Upper Extremity Sports Injuries*. Philadelphia: Mosby-Year Book, 1996, pp 420-422.)

the isometricity and camlike function of the reconstructed ligament.

The harvested graft is then placed in a figure-of-eight configuration through the transosseous tunnels and subsequently tensioned and sutured to itself with the elbow in 45 degrees of flexion and neutral varus-valgus alignment (Fig. 6, B and C). The elbow is taken through a full range of motion, and the graft is carefully inspected for isometricity, stability, and contact with the surrounding bone and tissues. A concurrent ulnar nerve transposition may be performed in cases of concomitant ulnar neuritis, ulnar nerve subluxation, or pathologic nerve constrictions noted at the time of surgery.[3,16] Routine transpositions are no longer performed, because of the risk of nerve injury secondary to segmental devascularization, intraoperative compression or traction, and postoperative scarring.

Postoperative complications most commonly involve injury to the medial antebrachial cutaneous and ulnar nerves. Recurrent instability secondary to rupture or stretch of the reconstructed ligament occurs infrequently.[15,16]

After a brief period of postoperative immobilization (7 to 10 days), active shoulder, elbow, and wrist range-of-motion exercises are initiated. Progressive resistive strengthening exercises of the wrist and forearm are begun after 4 to 6 weeks, including flexion, extension, pronation, and supination. At 6 weeks, progressive elbow-strengthening exercises are begun, but valgus stress of the elbow is avoided until 4 months. Shoulder range-of-motion exercises are begun early and maintained throughout the rehabilitation period. Strengthening exercises emphasizing the rotator cuff are instituted at 2 to 3 months, beginning with gentle isotonic exercises and progressing to the use of light weights.

A progressive throwing program beginning with light tossing is instituted at 3 to 4 months. Distance and speed are gradually increased as strength, power, and endurance of the shoulder and elbow muscles improve. By 6 months, patients may be allowed to begin lobbing the ball for a distance of 60 ft using an easy windup. At 7 months, throwing is advanced to 50% of maximum velocity; by 8 to 9 months, pitchers are permitted to return to the mound and progress to approximately 70% of maximum velocity. Careful attention is also paid to optimization of overall pitching mechanics, including those motions involving the torso and lower extremities. Functional performance, including rhythm, proprioception, and accuracy, is usually maximized by 12 to 18 months after surgery, at which time most athletes will be able to return to their preinjury level of activity.[3,15,16]

Results

Jobe et al[15] reported on 16 throwing athletes who underwent UCL reconstruction with ulnar nerve transposition. Ten (63%) were able to return to their preinjury level of activity.

Conway et al[16] subsequently reported on 70 procedures in 68 patients with valgus instability of the elbow; 14 elbows were treated by direct repair of the UCL, and 56 underwent ligamentous reconstruction with use of a free autologous tendon graft. Ten elbows (71%) in the direct-repair group and 45 (80%) in the reconstruction group demonstrated good or excellent results at a mean follow-up of 6.3 years. Seven patients (50%) in the repair group were able to return to preinjury competition levels, including 2 of 7 professional baseball players who had not undergone previous elbow surgery. In the reconstruction group, 38 (68%) were able to return to preinjury levels of competition, including 12 of 16 professional baseball players who had not undergone previous elbow surgery. The mean time to return to competition was 9 months in the repair group and 12 months in the reconstruction group. Previous surgery on the elbow was found to decrease the likelihood that athletes would return to their previous level of function. Twenty-two patients (40%) in the reconstruction group had preoperative symptoms related to the ulnar nerve, and 15 (22%) had ulnar nerve symptoms postoperatively. Six of these patients had paresthesias that resolved spontaneously, but 8 of the remaining 9 underwent revision procedures on the ulnar nerve. Two patients were unable to return to their sport because of persistent ulnar nerve symptoms.

In 1997, Jobe and co-workers[19] presented follow-up data on 83 athletes (54 professional, 18 collegiate, and 11 recreational) who underwent UCL reconstruction without ulnar nerve transposition. Only 3 patients (4%) had transient ulnar-nerve paresthesias postoperatively that completely resolved within 6 weeks. In 1 patient (1%), ulnar neuropathy, including motor weakness, resolved within 6 months postoperatively. Of the 33 patients who were evaluated at long-term follow-up, 27 (82%) had excellent results, and 4 (12%) had good results. The mean time for return to full, competitive throwing was 13 months (range, 6 to 18 months).

Valgus Extension Overload

Medial tension overload secondary to repetitive valgus stress can also result in injury to the surrounding structures of the elbow. Microtrauma and inflammation of the UCL occur, with eventual attenuation and insufficiency of the ligamentous complex. The elbow becomes subluxated in valgus during extension, leading to excessive force transmission to the lateral aspect of the elbow, as well as extension overload within the posterior compartment (Fig. 7). Compressive and rotatory forces are increased within the radiocapitellar articulation, leading to synovitis and the development of osteochondral lesions (osteochondritis dissecans and osteochondral fractures) that can fragment and become loose bodies.[20,21]

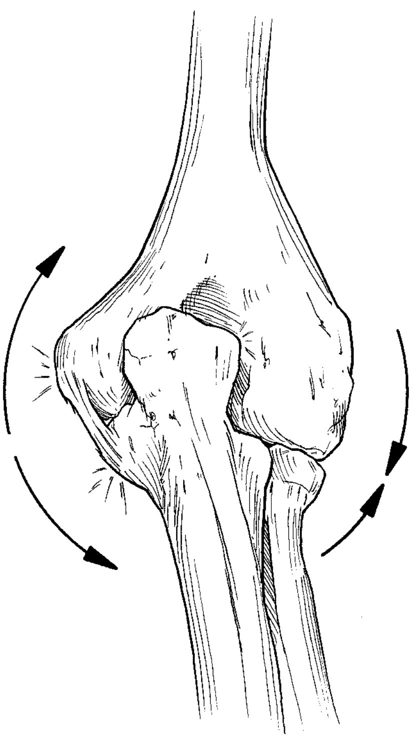
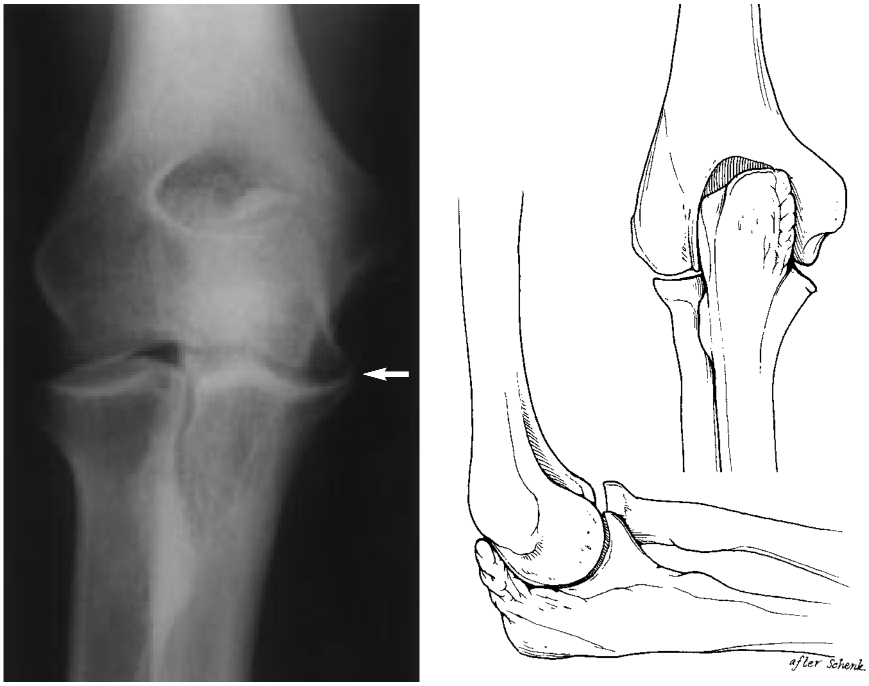


Figure 7 Medial tension overload secondary to repetitive valgus stress at the elbow, resulting in attenuation of the UCL complex medially, lateral radiocapitellar compression, and extension overload within the posterior compartment. (Adapted with permission from Kvitne RS, Jobe FW: Ligamentous and posterior compartment injuries, in Jobe FW [ed]: *Techniques in Upper Extremity Sports Injuries*. Philadelphia: Mosby-Year Book, 1996, p 414.)



A B

Figure 8 Valgus-extension overload of the posterior compartment resulting in traction spurs on the medial aspect of the ulnar notch **(A)**, as well as posteromedial osteophytes within the olecranon fossa **(B)**. (Reproduced with permission from Miller CD, Savoie FH III: Valgus extension injuries of the elbow in the throwing athlete. *J Am Acad Orthop Surg* 1994;2:261-269.)

Evaluation

Athletes may report symptoms of catching or locking when loose bodies develop. Medial tension overload resulting in valgus instability also leads to extension overload of the posterior compartment. The extension forces generated during the acceleration and follow-through phases of the throwing motion, which are normally absorbed by the ligamentous, capsular and muscular structures of the elbow, are excessively transmitted to the posterior compartment.[7,10-13,20]

Repeated impaction of the posteromedial olecranon in the olecranon fossa leads to chondromalacia and subsequent hypertrophic spur and osteophyte formation, especially in the medial aspect of the ulnar notch (Fig. 8). Posteromedial impingement secondary to encroachment on the olecranon fossa by osteophytes and scar tissue results in pain during the late acceleration and follow-through phases of throwing.[20,21] These hypertrophic osteophytes and traction spurs can frequently be observed on plain radiographs, especially on the axial olecranon view. Loose bodies and osteochondral lesions may occasionally be seen as well.[20,21]

Treatment

Nonoperative treatment consists of an initial period of rest, ice, and NSAIDs to alleviate pain and inflammation, followed by functional strengthening of the elbow and forearm. Stretching, isotonic, isokinetic, and isometric strengthening and conditioning exercises of the forearm are implemented. As strength improves, the athlete may begin plyometric exercises concentrating on the flexor-pronator musculature, as well as an interval-throwing program. Surgical intervention is recommended for patients who have failed nonoperative therapy or who have symptomatic traction spurs or loose bodies. There is a wide spectrum of underlying medial elbow stability; athletes who have failed conservative therapy and have persistent symptoms attributable to chronic valgus instability may also be candidates for operative management.

Elbow arthroscopy has replaced formal arthrotomy as the surgical procedure of choice for joint debridement and has been shown to have good results with low complication rates in symptomatic patients.[20-22] Chondromalacia of the ulnohumeral or radiocapitellar joint may be treated with debridement or drilling. Loose bodies and osteochondritic lesions can also be addressed. Debridement of hypertrophic synovium or scar tissue can be performed as well. Osteophytes and hypertrophic spurs in the posterior and medial aspects of the olecranon can be debrided to decompress the olecranon fossa. Undersurface tears of the UCL can also be visualized, although definitive treatment of the underlying instability cannot yet be performed arthroscopically.[17]

Postoperative rehabilitation is begun early to maintain range of motion as well as to strengthen the elbow gradually. Athletes usually progress through a graduated throwing program that allows them to return to full activity within 3 months.[20,21]

Reconstruction of the UCL is reserved for athletes with recalcitrant symptoms associated with chronic valgus instability for whom nonoperative management and less invasive procedures have failed. These athletes usually have medial elbow instability that potentiates symptoms of posteromedial impingement if left unaddressed.

Timmerman and Andrews[17] have described an undersurface tear of the UCL that correlates with detachment of the inner layer of the anterior bundle of the UCL from either the humerus or the ulna while the external portion of the UCL remains intact. These injuries are usually best visualized arthroscopically, and can be difficult to diagnose clinically or on MR imaging. In athletes with valgus extension overload and underlying chronic instability secondary to an attenuated, incompetent UCL, an open reconstruction of the UCL, along with adequate joint debridement (which may require an additional posteromedial arthrotomy), is necessary to ensure maximal functional outcomes.[8,17,20]

Medial Epicondylitis

Commonly referred to as "golfer's elbow," medial epicondylitis involves pathologic inflammatory changes of the flexor-pronator musculature. Medial epicondylitis occurs frequently in pitchers and other athletes who participate in activities that impart large valgus forces to the elbow. In athletes, however, it is still 7 to 20 times less common than lateral epicondylitis.[23,24] Overload from extrinsic valgus stresses and intrinsic muscular contractions predispose the flexor-pronator musculature to inflammation and injury, which commonly involve the humeral head of the pronator teres, the FCR, and occasionally the FCU.[7,10,23] The pronator teres has been shown in electromyographic studies to possess the highest activity level during the acceleration phase of throwing. Medial epicondylitis usually begins as a microtear in the interface between the pronator teres and FCR origins, with subsequent development of fibrotic and inflammatory granulation tissue.

Evaluation

Typically, patients are aggressive advanced-level athletes who present with an insidious onset of medial elbow pain worsened by throwing. On physical examination, they generally have tenderness over the flexor-pronator origin slightly distal and anterior to the medial epicondyle. Pain is usually exacerbated by resisted wrist flexion and forearm pronation.[23,24] It is also important to evaluate for concomitant valgus instability, as flexor-pronator overuse may predispose to medial ligamentous injury.[11]

Plain radiographs of the elbow may be normal, although medial ulnar traction spurs and UCL calcification can be observed in athletes with associated medial tension overload and potential valgus instability. Magnetic resonance imaging may demonstrate increased signal within the musculotendinous structures, and is a useful adjunct to more accurately define the underlying pathologic changes in the adjacent structures in the athlete with confounding medial elbow symptoms. In addition, in those with recalcitrant symptoms, MR imaging can be utilized to evaluate the integrity of the musculotendinous structures; full-thickness tears, if present, may necessitate more aggressive surgical management.

Electromyographic studies and cinematography have demonstrated that athletes with UCL injuries exhibit decreased pronator teres and FCR activity during the late-cocking and acceleration phases.[11] In patients with combined valgus instability and medial epicondylitis, treatment should be aimed at both entities to maximize elbow function. Authors have also reported a high incidence (up to 60%) of ulnar neurapraxia in patients with medial epicondylitis.[23-26] Therefore, it is important to evaluate for concurrent ulnar neuropathy and, if present, to direct treatment toward both the neuropathy and the epicondylitis to optimize the functional outcome.

Treatment

Initial nonoperative treatment consists of rest, ice, NSAIDs, and local modalities. Corticosteroid injections deep to the flexor-pronator mass may be utilized, although there is an associated risk of tendon attenuation with repeated injections. Recent studies have shown that steroid injections provide good short-term (up to 6 weeks) symptom improvement; results beyond this time frame are no different from those obtained with physical therapy and NSAIDs alone.[27] The next phase of nonsurgical treatment consists of throwing-technique enhancement and physical therapy. Splinting or counterforce bracing may also be a useful adjunct. Rehabilitation begins with wrist flexor and forearm pronator stretching and progressive isometric exercises. Eccentric and concentric resistive exercises are added once flexibility, strength, and endurance have improved. A gradual return to normal activity is subsequently allowed. Nonoperative treatment of medial epicondylitis has been shown by several authors to have excellent results, with success rates as high as 90%.[23-25]

Surgery is indicated for patients with refractory symptoms that do not respond to at least 6 months of a well-supervised therapy program. In these cases, a high correlation with full-thickness tendon tears has been reported.[25] The goals of surgical treatment include debridement of all inflamed and pathologic tissue, followed by secure tendinous repair. It is also important to minimize disruption of the flexor-pronator origin to prevent weakness.

An oblique skin incision is made over the medial epicondyle, followed by incision of the common flexor origin at the pronator teres–FCR interval.[25] Care must be taken to protect the ulnar nerve and the medial collateral ligament. Inflamed tissue is then sharply excised from the undersurface of the flexor-pronator mass, which is reattached to the medial epicondyle through multiple drill holes (Fig. 9).[25] After a brief period of postoperative immobilization (7 to 10 days), gentle passive and active elbow range-of-motion exercises are begun. Resisted wrist flexion and forearm pronation exercises are instituted at 4 to 6 weeks, followed by a progressive strengthening program. By postoperative month 4, patients are usually able to return to their normal activity levels.[23-25]

Results

Vangsness and Jobe[25] have reported that surgical debridement and reapproximation of the flexor-pronator musculature as treatment for refractory medial epicondylitis provides excellent pain relief while allowing athletes to return to high functional levels. They reported that 34 of 35 patients (97%) had good or excellent results, and 30 (86%) had no limitation in the use of the elbow. The patients' mean subjective estimate of elbow function improved from 39% of normal preoperatively to 98% postoperatively. Isokinetic and grip-strength testing revealed no functionally significant loss of strength, and all athletically active patients were able to return to their sport.[25]

Gabel and Morrey[26] reported similar success rates after surgical treatment of recalcitrant medial epicondylitis in 26 patients (30 elbows), but found associated ulnar neuropathy to be statistically correlated with a poor postoperative prognosis. Of 25 patients with no or only mild ulnar nerve symptoms, 24 (96%) had good or excellent results. In comparison, good or excellent results were noted in only 2 of 5 (40%) elbows with associated moderate or severe ulnar neuropathy, even with concurrent decompression or transposition of the ulnar nerve. Overall, however, the authors reported that 26 elbows (87%) had good or excellent results at an average follow-up interval of 7 years.

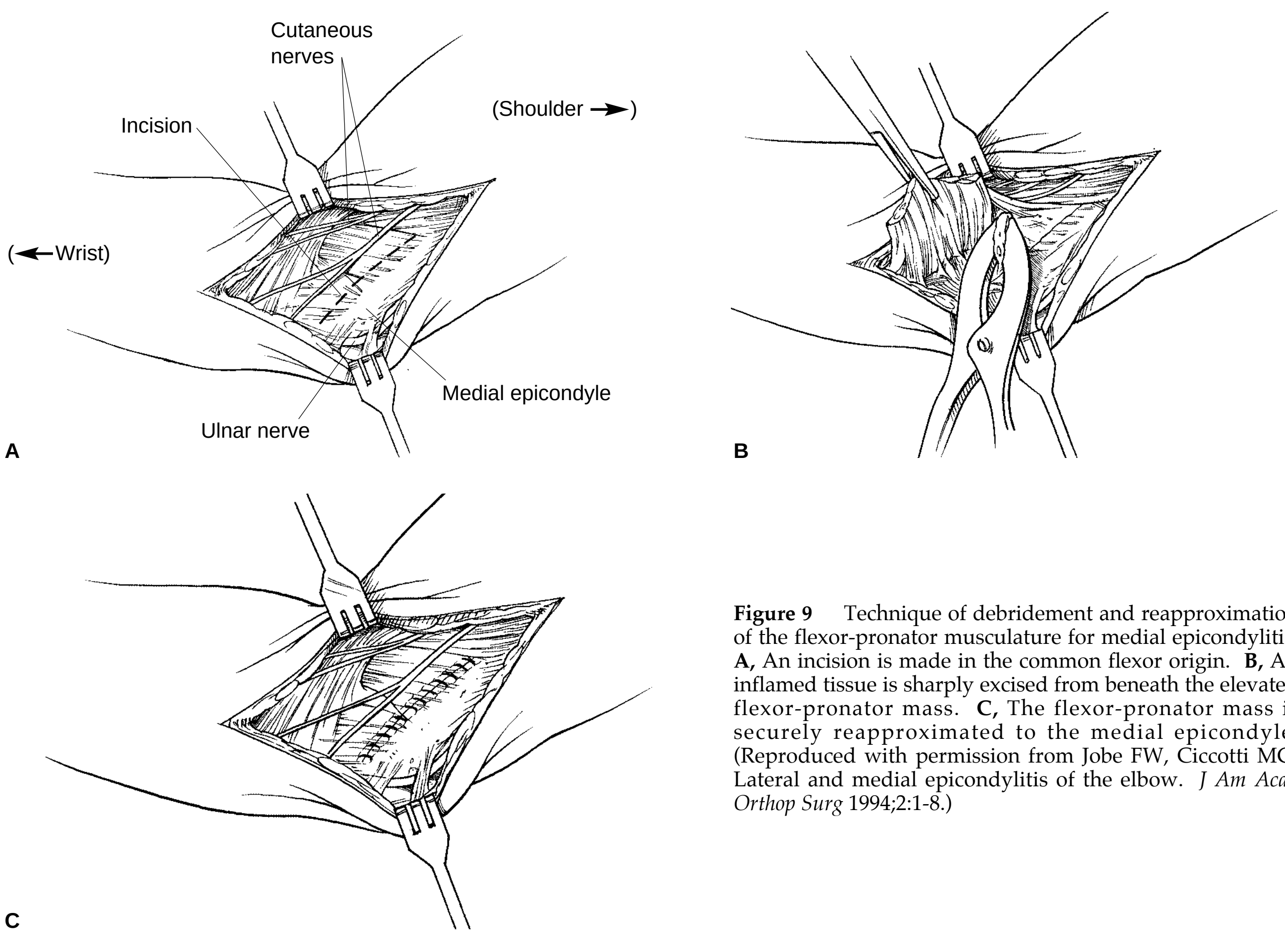


Figure 9 Technique of debridement and reapproximation of the flexor-pronator musculature for medial epicondylitis. **A,** An incision is made in the common flexor origin. **B,** All inflamed tissue is sharply excised from beneath the elevated flexor-pronator mass. **C,** The flexor-pronator mass is securely reapproximated to the medial epicondyle. (Reproduced with permission from Jobe FW, Ciccotti MG: Lateral and medial epicondylitis of the elbow. *J Am Acad Orthop Surg* 1994;2:1-8.)

Flexor-Pronator Injuries and Ruptures

The flexor-pronator musculature provides dynamic stability to the medial elbow and may be injured with repetitive valgus stress.[10-13] Continued activity and throwing beyond the limits of muscle fatigue may lead to injury and, occasionally, rupture of the flexor-pronator musculature.[18] These injuries usually occur during the acceleration and follow-through stages of the throwing motion, when forceful extension of the elbow and pronation of the forearm occur. Patients generally present with pain and swelling along the medial aspect of the elbow. On examination, there is usually tenderness at the medial epicondylar origin with pain that may be exacerbated by wrist flexion and elbow extension. It is important to evaluate for concurrent UCL injury. Minor partial injuries of the flexor-pronator musculature may be treated with rest, ice, and NSAIDs. More severe injuries and complete ruptures that compromise elbow stability require surgical repair.[18,20]

Hypertrophy of the pronator teres secondary to repetitive activity may result in compression of the median nerve and the development of pronator syndrome. Patients usually present with fatiguelike pain in the proximal volar aspect of the forearm that gradually worsens with continued activity. Symptoms are usually exacerbated by resistance to pronation of the forearm combined with wrist flexion. Surgical exploration, including elevation and division of the superficial head of the pronator teres, may be necessary to decompress the median nerve and provide symptomatic relief.

Although uncommon, compartment syndrome as a result of hypertrophy of the flexor-pronator musculature has also been reported. Patients describe pain localized to the medial elbow and proximal forearm that is worsened by increased throwing and activity, typically forcing pitchers to stop throwing after only a few innings. This condition can usually be prevented by adequate warm-up and proper timing of pitching to ensure adequate rest between workouts.[20]

Ulnar Neuropathy

Symptoms involving the ulnar nerve are very common in throwing athletes because of its superficial location, making it susceptible to injury. More than 40% of athletes with valgus instability develop ulnar neuritis secondary to irritation from inflammation of the UCL, and as many as 60% of throwers with medial epicondylitis also have concomitant ulnar nerve symptoms.[8,16,26]

Ulnar nerve entrapment results from both pathologic and physiologic responses to repetitive trauma.[28,29] Mechanical factors include compression, traction, and irritation of the nerve (Fig. 10).[8] Compression of the ulnar nerve proximal to the cubital tunnel may be due to a tight structure (arcade of Struthers or intermuscular septum) or to hypertrophy of an adjacent muscle (anconeus epitrochlearis or medial head of the triceps). Compression at the level of the cubital tunnel may result from osteophytes, loose bodies, synovitis, or a thickened retinaculum (Osborne lesion). Compression may also occur distal to the cubital tunnel at the FCU aponeurosis or at the deep flexor-pronator aponeurosis after the ulnar nerve passes between the two heads of the FCU.

The pressure within the ulnar nerve in the flexed elbow and extended wrist has been shown to be elevated to more than three times the resting level.[30] This has been attributed to nerve compression as

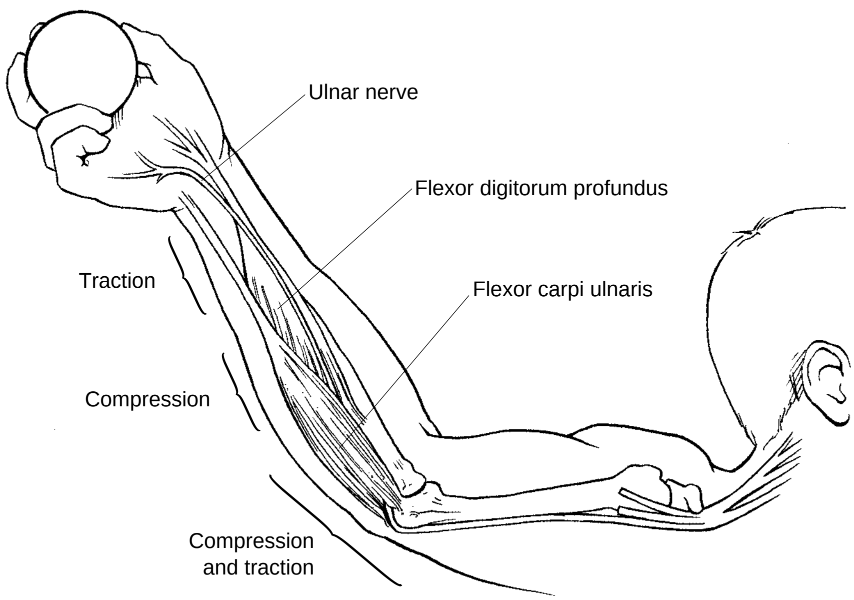


Figure 10 Pathologic forces acting on the ulnar nerve during the throwing motion. As valgus stresses are placed at the elbow, both traction and compression forces are produced on the nerve during the acceleration phase of throwing. (Adapted with permission from Boatright JR, D'Alessandro DF: Nerve entrapment syndromes at the elbow, in Jobe FW, Pink MM, Glousman RE, Kvitne RE, Zemel NP [eds]: *Operative Techniques in Upper Extremity Sports Injuries*. St Louis: Mosby-Year Book, 1996, p 521.)

well as to physiologic stretching of the nerve (the ulnar nerve normally moves 7 mm medially and elongates 4 to 7 mm during elbow flexion).[28,29] As the elbow flexes, increased tension on the arcuate ligament and the UCL also increases tunnel pressures. During the throwing motion, with further elbow flexion and wrist extension combined with shoulder abduction, the intraneural pressure may be elevated to as much as six times the resting level.[30] Any tethering of the nerve secondary to chronic changes associated with valgus overload (e.g., scar tissue, calcification of the UCL, traction spurs, degenerative changes in the ulnar groove) further increases intraneural pressures.[8,28,29,31] Traction on the nerve may also result from restriction of its normal mobility.[28,29] Additional friction on the nerve may be caused by ulnar nerve subluxation or dislocation, present in up to 16% of the population.[32] As a result, the cumulative effects of prolonged and repeated pressure elevations produce nerve fibrosis and ischemia.

Evaluation

Athletes with ulnar neuropathy usually present with intermittent medial elbow pain that may occasionally radiate down the medial aspect of the forearm into the hand. As inflammation progresses, they may also describe clumsiness or heaviness of the fingers on the involved side, as well as numbness and paresthesias in the little and ring fingers. Typically, these symptoms resolve with rest and are exacerbated by throwing or overhead activity. Athletes generally do not complain of weakness in the extremity—a late finding in ulnar neuropathy—as their performance is usually affected in the early stages before the development of motor changes. Painful popping or snapping sensations may also be experienced by patients with recurrent nerve subluxations or dislocations.

A careful neurologic evaluation of the neck and upper extremity is mandatory to rule out more proximal causes of neuropathy.[8,28,29] Palpation of the ulnar nerve in its groove through a full range of motion should be performed to examine for subluxation or dislocation. The nerve may feel "doughy" or thickened. Patients usually exhibit a positive Tinel sign at the cubital tunnel as well as a positive elbow flexion test (i.e., reproduction of pain, numbness, and paresthesias in the ulnar nerve distribution with maintained maximum elbow flexion and wrist extension for at least 1 minute).[33] The earliest sensory changes are noted with vibrometry or monofilament threshold tests. Nerve-ending density tests (e.g., two-point discrimination) become positive later as the condition progresses. Motor weakness, if observed, is seen earliest in the intrinsic hand muscles, such as the abductor digiti quinti and adductor pollicis, because the intrinsic motor fibers lie more superficial within the ulnar nerve in the cubital tunnel and are thus more susceptible to injury. Extrinsic weakness involving the flexor digitorum profundus and FCU is usually associated with more severe and advanced compression, as the extrinsic motor fibers lie deep within the nerve and are better protected.

Plain radiographs of the elbow, especially the cubital tunnel view, may be helpful in determining the presence of any associated pathologic changes in the bones. Magnetic resonance imaging may be used to identify the presence of soft-tissue masses that may be compressing the ulnar nerve, as well as to evaluate the status of surrounding soft-tissue structures.

Electrodiagnostic studies may be used as an adjunctive diagnostic tool, usually depending on the severity of the patient's condition. A negative electrodiagnostic study, however, does not rule out the diagnosis of ulnar neuritis.[28,31] Nerve-conduction velocities across the elbow are usually decreased only in cases of advanced or chronic nerve entrapment. A dynamic electromyogram may be more helpful when the diagnosis is equivocal and may aid in differentiating cervical, elbow, and more distal nerve involvement.

Thermography is currently being investigated as a diagnostic test for ulnar neuropathy. However, no conclusive evidence has yet been reported.[8,28,29,31]

Treatment

Nonoperative management of ulnar neuropathy usually begins with rest, ice, and NSAIDs. Immobilization of the elbow for a brief period (2 to 3 weeks) may be necessary, especially in cases of ulnar-nerve subluxation or dislocation. Local corticosteroid injections are not recommended. Although nonoperative treatment has had high success rates in the general population, many athletes—especially those with associated valgus instability—experience a recurrence of symptoms on resumption of throwing and ultimately require surgical intervention. Indications for surgery include failed nonoperative management, persistent ulnar-nerve subluxation, symptomatic tension neurapraxia, and concomitant medial elbow problems (e.g., valgus instability) that require surgery.

Surgical options include simple decompression, medial epicondylectomy, and anterior subcutaneous and submuscular transpositions. Simple decompression and medial epicondylectomy have been shown to have poor results in the overhead athlete and are thus not recommended. Simple decompression does not eliminate traction forces on the ulnar nerve, does not address pathologic changes within the cubital tunnel, and cannot be performed in the presence of nerve instability. Medial epicondylectomy is associated with high recurrence rates and destabilizes the nerve, which may predispose to subluxation or dislocation. In addition, injury to the UCL and the flexor-pronator musculature—important secondary dynamic stabilizers of the elbow—may occur, which may lead to valgus instability of the elbow with associated decreased forearm and wrist strength. Anterior subcutaneous transposition has been shown to have satisfactory results in the athletic population and has the advantage of minimizing disruption of the flexor-pronator musculature.[34] The subcutaneously transposed nerve, however, is vulnerable to direct trauma and may potentially develop instability.[8,28,29] In addition, the nerve may become secondarily compressed within the surgically created subcutaneous fasciodermal sling, leading to recurrence of symptoms.

Anterior submuscular transposition of the ulnar nerve decompresses all potential sites of entrapment and protects the transposed nerve from both direct and indirect trauma that may be encountered during athletic activity. The transposed nerve lies superficial to the pronator muscle mass and follows a direct course deep to the flexor muscle mass, where it lies adjacent to the median nerve in a fatty plane. This surgical approach also allows direct examination of the UCL and the underlying elbow joint for osteophytes, loose bodies, and other osseous abnormalities. In patients with concomitant valgus instability, repair or reconstruction of the UCL can be performed concurrently through this approach.[8,28,29,31]

A curvilinear incision along the course of the ulnar nerve, centered just posterior to the medial epicondyle, is made while preserving the medial antebrachial cutaneous nerve. The ulnar nerve is dissected and mobilized proximally from the arcade of Struthers, which must be released. A 2- to 3-cm portion of the medial intermuscular septum is removed to prevent tethering of the nerve once it is transposed anteriorly. The cubital tunnel retinaculum, including the arcuate ligament and the deep flexor-pronator aponeurosis band, is divided. The nerve is then mobilized distally past the medial epicondyle, preserving the motor branches and the vascular supply of the nerve, and is released from beneath the FCU aponeurosis as the nerve passes between the two heads of the FCU. The flexor-pronator interval is incised, the aponeurotic band of the flexor digitorum superficialis origin is released, and the common flexor origin is elevated off the medial epicondyle. The ulnar nerve is transposed anteriorly onto the remaining intact musculature overlying the ligamentous structures. The flexor origin is then reattached either by direct suture or through drill holes in the medial epicondyle (Fig. 11).

A potential disadvantage of submuscular ulnar nerve transposition is the lengthy postoperative rehabilitation period necessary after detachment and reapproximation of the flexor-pronator origin, which must be healed before the resumption of throwing. After a 1- to 2-week period of immobilization, pas-

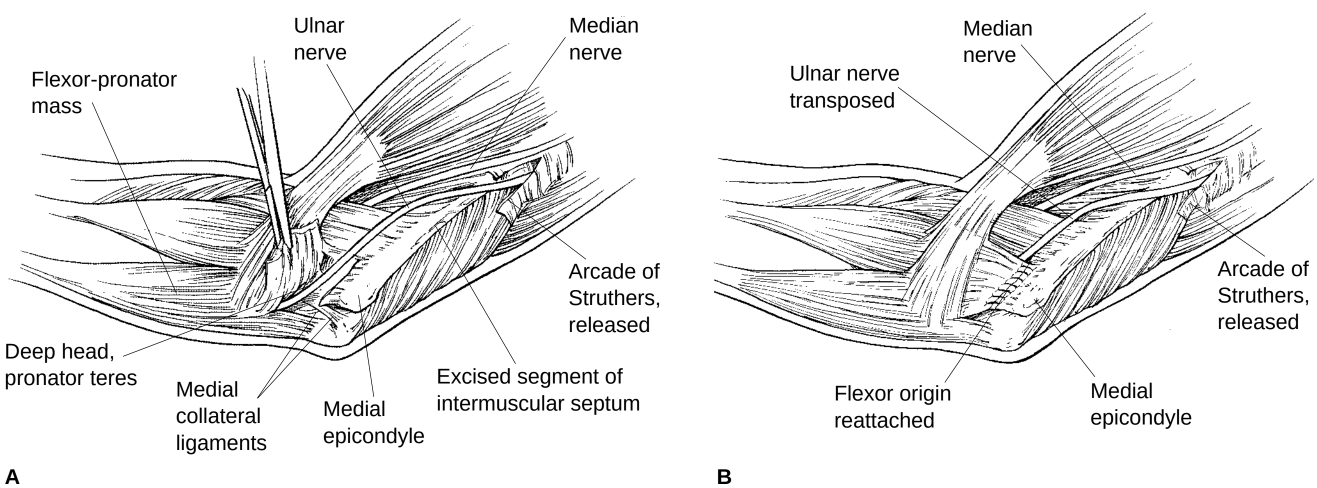


Figure 11 **A,** Anterior transposition of the ulnar nerve after elevation of the flexor-pronator mass, leaving the deep head of the pronator teres and the UCL complex intact. The transposed nerve lies next to the median nerve in a vascular, fatty bed. **B,** Completed submuscular transposition with reattachment of the flexor-pronator mass to the medial epicondyle. (Adapted with permission from Boatright JR, D'Alessandro DF: Nerve entrapment syndromes at the elbow, in Jobe FW, Pink MM, Glousman RE, Kvitne RE, Zemel NP [eds]: *Operative Techniques in Upper Extremity Sports Injuries*. St Louis: Mosby-Year Book, 1996, p 526.)

sive elbow range-of-motion exercises are begun. Active range-of-motion exercises are initiated at 3 to 4 weeks, followed by a strengthening program at 6 weeks. At 8 weeks, a supervised throwing program beginning with light tossing is initiated. Full, unrestricted activity is usually achieved by 4 to 6 months after surgery.

The outcome of this procedure in the athletic population depends on the degree of preoperative ulnar nerve involvement and the presence of associated medial elbow problems.[31] Patients with minimal sensory complaints and no motor weakness routinely recover completely and have an excellent prognosis for return to their previous level of function. However, less consistent results have been reported for patients who exhibit more advanced motor weakness and muscle wasting. Concomitant medial elbow problems, such as instability and degenerative changes, have also been associated with less consistent results. Patients with associated valgus instability should undergo repair or reconstruction of the UCL at the time of ulnar nerve transposition to optimize postoperative results. Overall, ulnar nerve transposition has been shown to result in good functional outcomes in the overhead athlete.[8,28,29,31,34]

Summary

The ligamentous, osseous, musculotendinous, and neural structures of the medial elbow are at considerable risk for a wide range of injuries as a result of either a single traumatic event or, more commonly, chronic repetitive stresses. During overhead throwing, the elbow is vulnerable to medial tension overload as a result of the tremendous valgus stresses that are generated, particularly during the late-cocking and acceleration phases. A thorough understanding of the underlying biomechanics and pathoanatomy, as well as a complete history and physical examination, are essential in the diagnosis and management of these injuries. It is also important to recognize that many of these injuries may occur in conjunction with each other.

In general, most symptomatic conditions unique to the throwing athlete respond well to nonoperative treatment protocols instituted at an early stage. However, for patients with refractory symptoms despite a supervised therapy program, surgical intervention is indicated. Ulnar collateral ligament reconstruction with an autologous graft has been shown to yield satisfactory results, with most athletes able to return to their previous level of activity. Advancements and refinements in arthroscopic techniques have resulted in improved and more successful methods of treatment of valgus-extension overload injuries. Continued modifications in surgical techniques for the treatment of ulnar neuropathy and injuries to the flexor-pronator musculature have also resulted in improved functional results. Common underlying factors in the enhancement of functional results include improvements in rehabilitation programs, which play an integral role in the restoration of function in throwing athletes. Future research on the anatomy, biomechanics, and pathophysiology associated with overhead activities may aid in prevention and treatment of many repetitive overuse elbow injuries.

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