The Thrower's Elbow

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KEYWORDS

• Overhead throwing athlete • Ulnar collateral ligament • Tommy John • Ulnar subluxation • Olecranon impingement • Capitellar OCD

KEY POINTS

- Most elbow injuries occur as a result of the stresses incurred during the acceleration phase.
- During overhead throwing, a large valgus force on the elbow created by humeral torque is countered by rapid elbow extension, creating significant tensile stress along the medial compartment, shear stress in the posterior compartment, and compressive stress in the lateral compartment.
- The docking technique in ulnar collateral ligament (UCL) reconstruction demonstrated a lower complication rate and a greater rate of return to play compared with the Jobe technique.
- During surgical management of valgus extension overload syndrome, it is recommended that only the osteophyte and no native olecranon be removed to prevent iatrogenic instability.

INTRODUCTION

The elbow undergoes significant stress during the throwing motion of an overhead athlete. The forces generated in the various phases of the throwing arc are distributed through the soft tissue and bone of the elbow joint. In athletes, such as baseball players, repetition leads to attritional damage to the elbow. The specific constellation of injuries suffered in baseball and other overhead sports, such as softball, football, tennis, and javelin, are well documented. These injuries include (1) medial UCL tears, (2) ulnar neuritis, (3) flexor-pronator injury, (4) medial epicondyle apophysitis or avulsion, (5) valgus extension overload syndrome with olecranon osteophytes, (6) olecranon stress fractures, (7) osteochondritis dissecans (OCD) of the capitellum, and (8) loose bodies.[1]

Approximately 55% of high school students participate in sports, and in 2013, softball and baseball ranked as the forth and third most popular high school sports for girls and boys, respectively.[2] More than 2 million high school athletes are seen for sports-related injuries on an annual basis. Although the rate of elbow injuries is relatively low, the total number of such injuries is significant due to the high number of participants. With increasing rates of adolescent and young adults participating in athletics, knowledge regarding the diagnosis and treatment of thrower's elbow remains prudent. The elbow joint is complex, however, and understanding the management of thrower's elbow injuries begins with understanding the anatomy and pathophysiology.

The purpose of this review article is to describe the biomechanics of the throwing motion, the examination of the elbow, the diagnostic evaluation, and the diagnosis and treatment of the spectrum of elbow injuries common to a thrower (**Box 1**).

FUNCTIONAL ANATOMY

The elbow is a ginglymus joint that allows flexion-extension through the ulnohumeral articulation and pronation-supination through the radiocapitellar articulation. It is one of the most congruent joints in the body, with the trochlea covered by articular cartilage over a 300° arc. The bony anatomy of the proximal ulna and olecranon fossa provides primary stability at opposite ends of terminal

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Box 1
Thrower's elbow pain differential diagnosis

UCL injury
Ulnar neuropathy
Flexor-pronator injury
Medial apophysitis or epicondyle avulsion
Valgus extension overload syndrome
Olecranon stress fracture
OCD of the capitellum

motion: less than 20° and greater than 120° of flexion. The radial head provides secondary restraint to valgus stress at 30°. The primary stability during the functional arc of an overhead athlete (20°–120°) emanates from the soft tissue restraints.[3–5] Furthermore, much of the stability derived from the osseous structure resists against varus stress with the elbow in extension.[5–7]

The soft tissue structures that provide static valgus elbow stability vital to overhead throwing include the anterior joint capsule, the UCL complex, and the radial collateral ligament complex. The UCL is composed of 3 bundles: an anterior, a transverse oblique and a posterior. The anterior bundle provides valgus stability throughout the entire range of motion (ROM) and consists of anterior and posterior bands that originate from the inferior aspect of the medial epicondyle and insert at the sublime tubercle on the medial aspect of the coronoid process (**Fig. 1**A–D).[5–8] The anterior band provides primary stability against valgus stress from full extension to 90° of flexion and secondary restraint at flexion greater than 90°. The posterior band, which is nearly isometric, provides functionally important restraint between 60° and full flexion, an arc of motion pivotal in the motion of an overhead throwing athlete.[9,10]

The oblique bundle (transverse ligament) lies at the distal-medial aspect of the joint capsule and does not actually cross the elbow joint. The posterior bundle is thinner and weaker than the anterior bundle and provides secondary elbow stability at greater than 90° of flexion.[5,6,9]

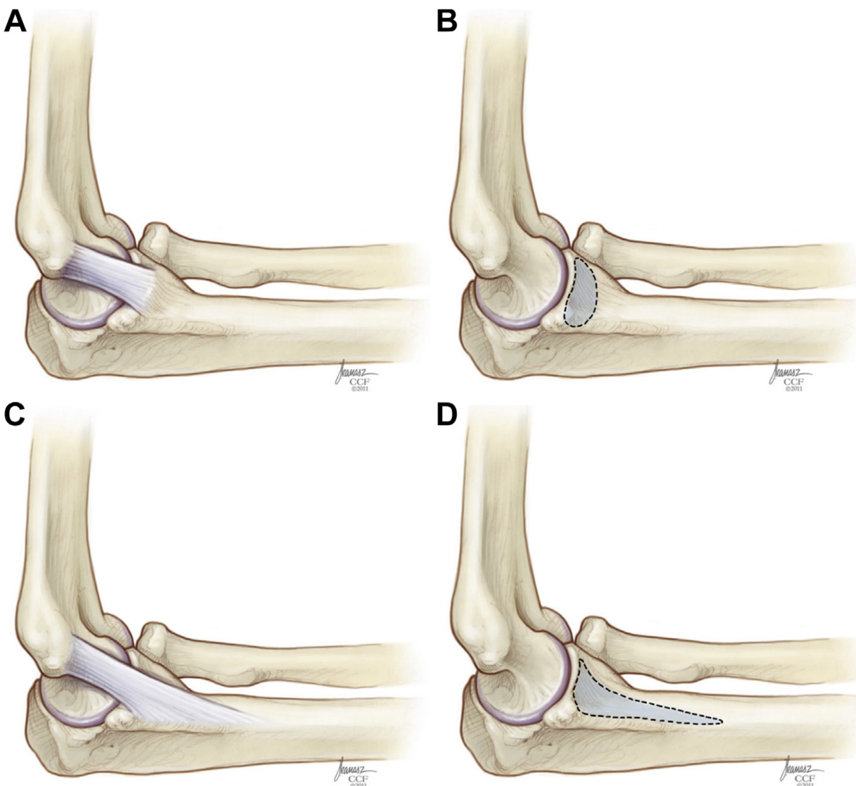

Fig. 1. Anatomy of the anterior bundle of the medial UCL of the elbow. Illustrations demonstrating traditional anatomy of the medial ulnar collateral ligament anterior band (*A*), traditional ulnar footprint (dashed line) (*B*). Illustrations of recently identified anatomy of the medial ulnar collateral ligament anterior band (*C*) and footprint at an osseous ridge that extends from the sublime tubercle to just medial to the ulnar insertion of the brachialis muscle tendon[160] (outlined with dashed line) (*D*). (*Courtesy of* Clinic Center for Medical Art & Photography © 2014, Cleveland. All Rights Reserved; with permission.)

The dynamic elbow stabilizers consist of the muscles in the flexor-pronator mass that originate off the medial epicondyle. This mass consists of the pronator teres, flexor carpi radialis, palmaris longus, flexor digitorium superficialis, and flexor carpi ulnaris (FCU), which functionally stabilize against valgus stress during active motion.[11]

Lastly, the ulnar nerve courses the medial elbow joint emanating from the arcade of Struthers and passing into the posterior compartment of the arm through the medial intermuscular septum. The nerve, along with a rich plexiform of vessels, enters the cubital tunnel just posterior to the medial epicondyle. The UCL complex forms the floor of the cubital tunnel whereas the roof is composed of the arcuate (Osborne) ligament. Distally, the ulnar nerve passes between the 2 heads of the FCU and rests on the flexor digitorum profundus.

BIOMECHANICS OF THROWING

Overhead throwing sports are typically grouped together because the general motion is similar. Thus, a baseball pitcher's throwing motion, which is the most heavily investigated model, serves as the basis for understanding biomechanics. The baseball pitch is divided into 6 stages of coordinated upper extremity, trunk, and lower extremity movements (**Fig. 2**).[7,12–18] The stages specific to elbow motion include

I. Wind-up: the elbow is flexed and the forearm is pronated as the arm is initially overhead and returns to an adducted position.
II. Early cocking: the elbow maintains flexion and forearm pronation as the glenohumeral joint is abducted and externally rotated and the leading lower extremity is advanced.
III. Late cocking: involves increasing elbow flexion between 90° and 120° and forearm pronation to 90° while maximizing shoulder abduction and external rotation.
IV. Acceleration: the elbow is rapidly extended as the humerus adducts and internally rotates during a coordinated forward movement of the upper extremity and trunk. This stage terminates with ball release over 40 to 50 milliseconds, during which the elbow accelerates as much as 600,000°/s.[5,19]
V. Deceleration: rapid deceleration occurs at a rate of 500,000°/s^2 over a time span of 50 milliseconds as excess kinetic energy is dissipated.[7,12–16,19]
VI. Follow-through: the elbow reaches full extension and throwing motion terminates.

Most elbow injuries occur as a result of the stresses incurred during stage IV or the acceleration phase where valgus forces reach as high as 64 Nm.[20] The valgus torque concentrate to the medial elbow, primarily the anterior bundle of the UCL.[11,14] Approximately 300 N of shear force is experienced by the medial elbow.[20] Concomitantly, compressive forces at the lateral radiocapitellar joint reach 500 N.[20] Nevertheless, modification to throwing biomechanics may not necessarily lead to improved clinical outcomes because the stresses from repetitive throwing may be the driving force to injury.

DEVELOPMENTAL CHANGES OF THE ELBOW

The repetitive stresses at the elbow and shoulder from throwing can lead to developmental changes, and, eventually, injury in young athletes. Small adaptive changes proximally may affect more distal segments of the kinetic chain.[21] For instance, Garrison and colleagues[22] found deficits

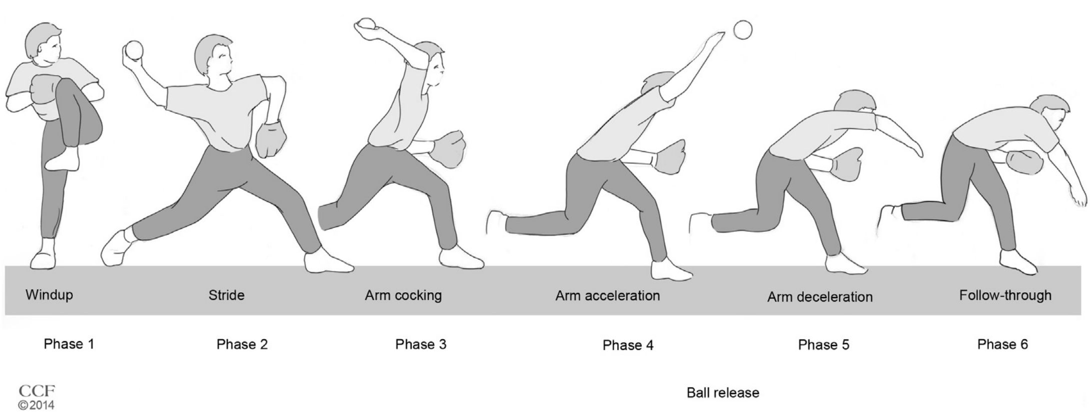

Fig. 2. Overhead throwing phases. (*Courtesy of* Clinic Center for Medical Art & Photography © 2014, Cleveland. All Rights Reserved; with permission.)

in total ROM of the shoulder were associated with UCL tears in a cross-sectional study of high school and collegiate baseball players. Changes in the shoulder include increase in external rotation from humeral retroversion and capsular laxity as well as decrease in internal rotation from osseous adaptations.[23–26] Polster and colleagues[27] demonstrated that the mean dominant arm humeral torsion in professional pitchers was 38.5° ± 8.9° (range, 23.0°–53.9°) compared with 27.6° ± 8.0° (range, 11.8°–45.0°) in the nondominant arm. This adaptation may be protective because the investigators found a higher incidence of severe injuries in players with lower degrees of dominant torsion. Burkhart and colleagues[28] proposed that increased humeral torsion leads to greater external rotation of the shoulder during late cocking, thus providing a longer throwing arc and potentially a greater peak velocity that increases the stresses experienced by the elbow. Distally at the elbow, Hang and colleagues[29] found that 94% of competitive young baseball players had radiographic signs of medial epicondylar apophyseal hypertrophy.

In overhead throwing athletes, understanding the difference between commonly seen asymptomatic adaptive changes and clinically significant pathology is critical in providing proper care to these athletes.[30] In a study of asymptomatic professional baseball players, Kooima and colleagues[31] found an 87% prevalence of chronic UCL injury and an 81% prevalence of posteromedial osteochondral injury. In asymptomatic major league baseball pitchers, increased medial laxity on valgus stress is not uncommon.[32,33] In a skeletally immature or adolescent thrower, the physis or apophysis absorbs the stresses of throwing and undergoes changes.[29,34] With time, asymptomatic changes may progress to symptomatic pathology with increased stress or frequency beyond reparative potential.

PATHOPHYSIOLOGY OF ELBOW INJURIES

King and colleagues[35] described a spectrum of elbow injuries in baseball pitchers from medial tension overload to extension overload to lateral compression overload. These injury patterns can be explained by one mechanism: valgus extension overload syndrome.[36] During overhead throwing, a large valgus force on the elbow created by humeral torque is countered by rapid elbow extension creating significant tensile stress along the medial compartment, shear stress in the posterior compartment, and compressive stress in the lateral compartment.[20,30] Repetitive, near-failure tensile stresses create microtrauma and attenuation anterior bundle of the UCL, leading to progressive valgus instability. Continued shear stress and impingement in the posterior compartment lead to olecranon tip osteophytes, loose bodies, and articular damage to the posteromedial trochlea in the continuum of valgus extension overload syndrome (Fig. 3A, B). As the UCL becomes incompetent, the osseous constraints of the posteromedial elbow become important stabilizers during throwing. Subtle laxity in the UCL also leads to stretch of the other medial structures, including the flexor-pronator mass and ulnar nerve. Extrinsic valgus stresses and intrinsic muscular contractions of the flexor-pronator mass lead to tendonitis. Completing the spectrum of thrower's elbow,

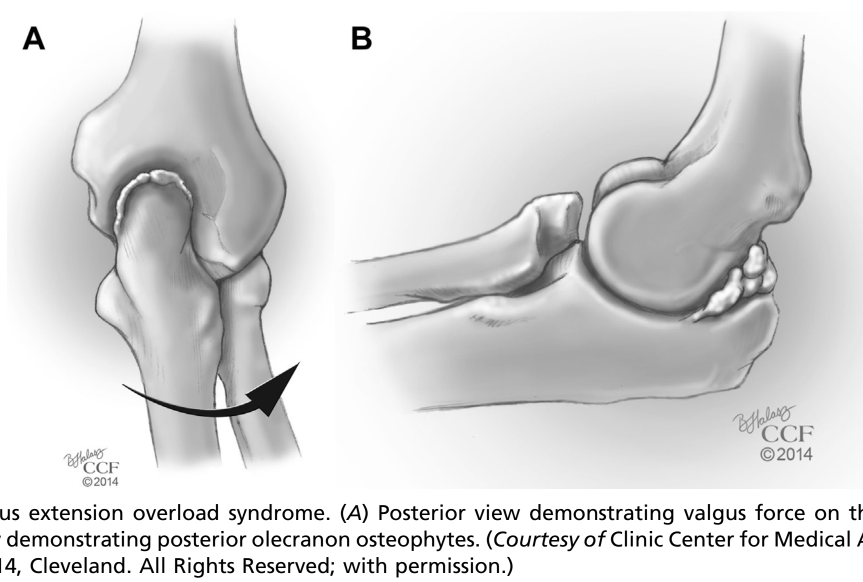

Fig. 3. Valgus extension overload syndrome. (*A*) Posterior view demonstrating valgus force on the elbow. (*B*) Lateral view demonstrating posterior olecranon osteophytes. (*Courtesy of* Clinic Center for Medical Art & Photography © 2014, Cleveland. All Rights Reserved; with permission.)

ulnar neuropathy is common given the superficial position of the nerve. The nerve is susceptible to injury from traction, compression, and irritation at the medial aspect of the elbow. In any overhead throwing athlete, UCL attenuation or failure must be ruled out but should not be the only pathology considered.

HISTORY AND PHYSICAL EXAMINATION

A thorough history starts with knowing the patients, their sport, and their level of competition. Asking an athlete specifically about the chief complaint may help delineate between primary (ie, decreased velocity on pitch from UCL attenuation) and secondary processes (ie, pain from posteromedial impingement). Complaints may include pain, decreased motion, mechanical symptoms (clicking, locking, popping, and so forth), instability, and paresthesias as well as throwing-specific symptoms. Changes in accuracy, velocity, stamina, and strength aid in diagnosis and serve as markers to measure improvement. Timing of symptoms may not always be clear; however, if a specific injury or event occurred, it is important to know when, how, and whether there were any antecedent or prodromal symptoms. Any changes in a training or throwing regimen should be noted, including pitch counts, innings pitched, games pitched, and rest between pitching for baseball players.

The timing, onset, and frequency of pain are important to determine.[20,37] In athletes with valgus instability, approximately 85% experience pain during the late cocking and early acceleration phases of throwing.[38]

Physical examination starts with inspection of an athlete's posture, arm position, muscle mass, and skin. Any asymmetries compared with contralateral extremity should be detected. Elbow flexion to approximately 70° allows the greatest intracapsular volume and may be an indication of effusion.[6] Flexion, at a lesser degree, may be secondary to an extension block from posteromedial olecronan osteophytes. With the elbow in extension and forearm in full supination, the carrying angle can be determined. The normal carrying angle is 11° in men and 13° in women.[39] Lastly, inspect the skin for any ecchymoses or prior incisions.

Palpate the olecranon, medial and lateral epicondyles, radial head, and soft spot to establish the important landmarks of the elbow. Tenderness on palpation of these landmarks may indicate acute fracture, stress fracture, or tendonitis. In skeletally immature athletes, tenderness may indicate injury to the apophysis or physis. Lateral olecranon tenderness to palpation may indicate a stress fracture whereas proximal medial tenderness may be related to impingement. Lastly, palpation of the radial head during an arc of passive supination and pronation can help identify osteochondral defects, joint incongruency, and injury to the annular ligament.

Tenderness over the insertions of the various tendons around the elbow can indicate microtrauma or inflammation. The flexor-pronator mass lies just distal to the medial epicondyle with the arm at 90°. Having patients actively flex the wrist helps identify the tendinous mass, accentuate any pain, and differentiate from UCL pathology. Ranging the elbow from 90° of flexion to approximately 50° to 70° of flexion helps to displace the flexor-pronator mass anterior and exposing the UCL just posterior. Focal swelling and tenderness along the UCL should be concerning. As discussed previously, the UCL has 3 distinct bundles, with the anterior bundle running from the inferior aspect of the medial epicondyle to the medial aspect of the coronoid process.

Directly posterior and distal to the medial epicondyle lies the cubital tunnel, which encloses the ulnar nerve. Palpation of the ulnar nerve from proximal at the arcade of Struthers to distal at the FCU should not elicit any pain. Furthermore, percussion of the nerve should be benign (Tinel sign), but radiating symptoms into the ulnar hand and 2 digits indicate ulnar nerve pathology. The ulnar nerve may be symptomatic, however, even if tenderness is not appreciated. The elbow should be fully extended and then flexed with and without pressure on the nerve proximal to the medial epicondyle. Anterior subluxation of the ulnar nerve can cause local or radiating discomfort.[40,41]

Stability of the elbow can be assessed with patients in either the supine or seated position. In the supine position, the humerus is stabilized in maximal external rotation and 30° of flexion.[4,42,43] With the forearm fully pronated and the elbow flexed 20° to 30° to unlock the olecranon from the olecranon fossa, valgus stress is gradually applied to the elbow and opening is assessed.[44] Less than 1 mm of opening and a firm endpoint should normally be appreciated during the manual valgus stress test. Physiologic laxity may be present, however, and it is more appropriate to compare the stability with the contralateral extremity. Increased opening of the joint space or reproduction of a patient's pain should raise suspicion of injury to the anterior band of the anterior bundle of the UCL.[7,38,44]

The milking maneuver tests the posterior band of the anterior bundle of the UCL. In this maneuver, the forearm is supinated fully and the elbow is flexed beyond 90° (approximately 120°) and the humerus is at the athlete's side (**Fig. 4**).[7] The

Fig. 4. Milking maneuver for evaluation of the UCL. The forearm is supinated fully and the elbow is flexed beyond 90°. The thumb is then pulled laterally by the athlete's contralateral extremity, creating a valgus force on the elbow. Pain, instability, or apprehension is indicative of injury to the UCL.

thumb is then pulled laterally by the examiner or the athlete's contralateral extremity, creating a valgus force on the elbow. Pain, instability, or apprehension is indicative of injury to the UCL.

Lastly, with the patient in the seated position and the forearm supinated, the elbow is slightly flexed. With one hand on the posterior aspect of the distal humerus and the other hand on the volar forearm, the elbow is rapidly extended while applying a valgus stress.[36] Pain with this valgus extension overload test indicates impingement of the posteromedial tip of the olecranon on the medial wall of the olecranon fossa.

IMAGING MODALITIES

Standard anteroposterior, lateral, and oblique radiographs are obtained of the elbow. Radiographs may demonstrate calcification of the UCL, osteophytes adjacent to the UCL, olecranon fossa osteophytes, sclerotic OCD lesions, and/or loose bodies. Fluoroscopy is useful in assessing for medial instability by stressing the elbow and comparing with the contralateral extremity. Asymmetry alone, however, may not be enough to diagnose acute injury to the UCL because asymptomatic pitchers have been found to have some laxity in pitching elbow compared with the contralateral extremity.[33,45] Nevertheless, greater than 3 mm of opening is concerning for UCL injury and valgus instability.[5,7]

Conventional radiographs are not sensitive for detecting stress injuries in bone. The sensitivity of initial radiographs is as low as 15% and becomes positive over time in only 50% of patients.[46,47]

Radionuclide bone scanning is sensitive but less specific for detecting osseous stress injuries, even in their early stages.[48–52] Radionuclide technetium Tc 99m diphosphonate triple-phase scanning can provide the diagnosis as early as 2 to 8 days after the onset of symptoms.[53]

CT can help differentiate between stress fractures and other conditions that may show increased uptake on bone scan (**Fig. 5**). A CT scan is not sensitive, however, in detecting stress injuries in their early stages.[54]

MRI can detect early stress changes as well as muscle and tendon changes, loose bodies, osteochondral injuries, olecranon osteophytes, and neurologic changes to thrower's elbow. MRI is useful in evaluating UCL avulsions, partial ligamentous injuries, midsubstance tears, and the status of the surrounding soft tissues (**Fig. 6**). MRI has been found 57% sensitive and 100% specific in detecting UCL injuries.[55–58] MRI arthrography seems to improve the sensitivity of detection of UCL tears, with saline injection improving the

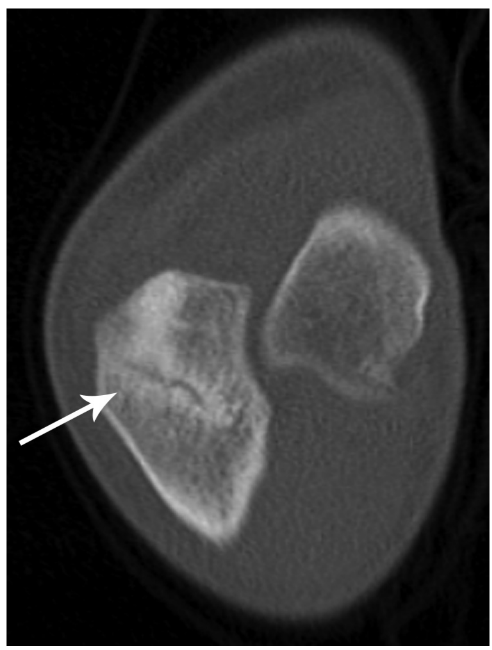

Fig. 5. Axial slice of a CT scan of a professional pitcher demonstrating a stress fracture of the olecranon (*arrow*).

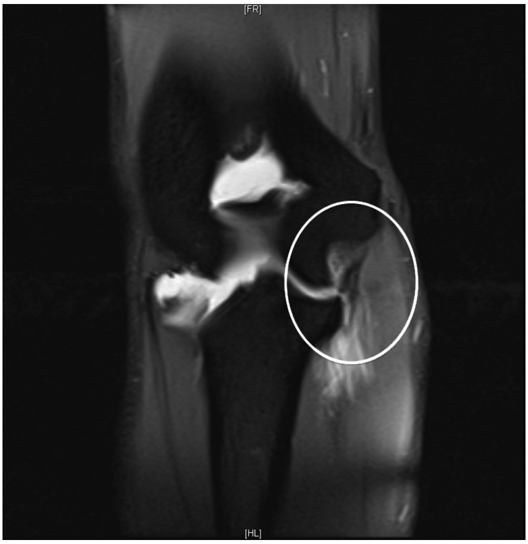

Fig. 6. Coronal slice of an MRI demonstrating a medial UCL tear (*circle*).

sensitivity of UCL detection to 92%.[56] Potter[58] and Gaary and colleagues[57] have reported similar sensitivity and specificity with nonarthrogram MRI using special sequences at the Hospital for Special Surgery. Timmerman and colleagues[59] compared CT arthrogram with both contrast-enhanced MRI and nonenhanced MRI and found a sensitivity of 86% and specificity of 91%.

ULNAR COLLATERAL LIGAMENT INJURIES

Depending on the extent of damage to the UCL, specific treatment programs can be implemented. Complete disruption of the anterior bundle of the UCL can destabilize the elbow against valgus stress encountered during the throwing motion. Partial tears of the UCL can be managed nonoperatively in low-demand patients[3,60]; however, results in overhead throwing athletes have not been promising.[61] Overall, treatment options for UCL injury include nonoperative rehabilitation, direct ligament repair, or free-tendon graft reconstruction.

Nonoperative Treatment

After a complete evaluation and diagnosis of a UCL injury through physical examination and radiologic studies, physician and athlete must agree on the appropriate course of care. Nonsurgical treatment measures are indicated for the initial treatment of sprains of the medial UCL in the vast majority of cases. Patients who present with findings consistent with a partial tear of the UCL, grade I and some grade II, should be initially placed on a period of active rest for 6 to 12 weeks. It is important to protect the elbow from valgus stress, including throwing, for a minimum of 6 weeks. Using a criteria-based rehabilitation program assures that a patient's progress is appropriate for individual rehabilitation potential at each criteria stage.

Initially, athletes are treated with cryotherapy, pain-modulating electrotherapy modalities, antiinflammatory medication, and a hinged elbow brace restricting full extension because relief of pain and reduced inflammation dictate the subsequent rehabilitation strategies. The early focus of rehabilitation is in regaining or maintaining elbow and shoulder ROM in conjunction with shoulder-strengthening exercises. Scapular-based exercises are initiated immediately for both nonoperative and operative UCL rehabilitation programs. Patients can continue core- and lower quarter–strengthening exercises performed without gripping heavy weight or resistance. Once a patient has regained full pain-free elbow ROM, there is a progression from isometric to isotonic upper arm–based to a forearm-based resistance program focusing on strengthening the medial dynamic stabilizers with emphasis on the pronator teres, FCU, and flexor digitorum superficialis. Hamilton and colleagues[13] found that when UCL stabilizing capabilities are compromised, activity of these medially based muscles is decreased. A criteria-based return-to-throw program is initiated when functional patterns, with resistance, consistent for pitching are pain-free and valgus stress testing is negative. Retting and colleagues[62] evaluated 31 throwing athletes treated nonoperatively for a UCL injury with a minimum of 3 months of rest with rehabilitation. They reported a 42% return to competitive throwing at the same level or higher at an average of 24.5 weeks.

Recent interest in platelet-rich plasma (PRP) has led to a broad array of applications. Podesta and colleagues[63] evaluated their outcomes in 34 athletes with partial UCL tears who received 1 PRP injection to the elbow after failing 2 months of typical nonoperative management; 30 of the 34 returned to play at preinjury level at an average of 12 weeks.

Operative Treatment

Overhead throwing athletes with complete disruption of the anterior bundle of the UCL are candidates for surgical intervention if they wish to return to preinjury level of play. Athletes with partial tears unable to return to competitive throwing (or other overhead sport) due to continued medial elbow pain despite completion of an adequate course of nonoperative treatment are considered candidates for surgical treatment as well. The goal of surgical reconstruction of the medial UCL is restoration of valgus stability to the elbow.

Direct primary repair of the UCL is reserved for acute avulsion injuries from either the humeral origin or coronoid insertion.[38,64,65] UCL injuries in throwing athletes are typically present, however, as attenuated ligaments or midsubstance tears. Chronic repetitive microtrauma leads to significant scarring and subsequent inability for effective primary repair of the UCL.[61,66] Limited studies of results after primary repair of medial UCL injuries exist.[38,67,68] Level IV retrospective series have shown inconsistency in documentation of athletic level and return to play.[65,66] A case series of 47 adolescent athletes (mean age 17.2 years) by Savoie and colleagues[68] reported 93% good to excellent results after primary repair of proximal and distal ligament avulsion injuries using suture anchors or bone tunnels.

Meanwhile, studies comparing repair with reconstructive techniques have shown better results with the latter. Conway and colleagues[38] treated 14 overhead throwing athletes with UCL deficiency with primary repair and 56 with graft reconstruction. In the repaired group, 50% of the athletes returned to preinjury level of sport, and, overall, 71% had good or excellent results. In the reconstruction group, 68% returned to preinjury level of sport, whereas 80% had good or excellent results. Andrews and Timmerman[69] evaluated 72 professional baseball players who underwent elbow surgery and found that neither of the 2 athletes who underwent primary repair of the UCL returned to sport, whereas 12 of the 14 who underwent reconstruction were able to return to play. Lastly, Azar and colleagues[45] reported results of 67 patients treated with UCL primary repair or reconstruction with 12- to 72-month follow-up; 5 of the 8 patients (63%) treated with repair returned to preinjury level of play compared with 48 of 59 (81%) in the reconstruction group.

Frank Jobe first performed reconstruction of the elbow medial UCL on September 25, 1974, on Los Angeles Dodgers left-handed pitcher Tommy John. John returned to pitching in 1976 and over the next 13 seasons went on to pitch 2500 innings, compiling a record of 164 wins and 125 loses, and never having another significant problem with his elbow. John's successful return to pitching after surgery revolutionized the treatment of athletes with injuries to the medial UCL and popularized the procedure, known as *Tommy John surgery*.

In the Jobe 3-ply technique, the ipsilateral palmaris longus tendon is harvested as a graft.[38,64] Other suitable options for graft material include the contralateral palmaris longus tendon and gracilis tendon. Allograft gracilis tendon may also be used. Savoie and colleagues[70] performed hamstring allograft medial UCL reconstruction in 116 overhead athletes. Of these 116 athletes, 110 returned to play with 88% playing at or above preinjury level.

Two converging drill holes are created in the sublime tubercle of the proximal ulna, creating a bone tunnel, and 2 divergent drill holes are created in the medial epicondyle (**Fig. 7**). With the assistance of a suture passer, the graft is passed first through the bone tunnel in the ulna. It is then crossed over itself as the posterior limb of the graft is passed up the anterior tunnel into the medial epicondyle with the anterior limb going into the posterior tunnel. The limb within the posterior tunnel is then brought up around the back of the epicondyle and passed distally back into the anterior tunnel, exiting at the entrance point into the medial epicondyle. With the elbow positioned in approximately 30° of flexion and the forearm in neutral rotation, with a slight varus moment applied to the elbow, the graft is tensioned and sutured to itself, resulting in a 3-ply graft reconstruction. Any remaining native ligament is then incorporated into the graft, reinforcing the construct.

The classic Jobe surgical technique involves exposing the UCL by reflecting the flexor-pronator origin off the medial epicondyle and anteriorly transposing the ulnar nerve in a submuscular position. Early published results of medial UCL reconstructions performed using this technique reported a high incidence of postoperative ulnar nerve complications.[38,64] Thompson and colleagues reported a 31% incidence of postoperative ulnar nerve dysfunction whereas Smith and colleagues found an incidence of 21%. In an effort to minimize these complications, contemporary techniques use a muscle-splitting approach through the FCU.[71,72] Additionally, most surgeons currently reserve ulnar nerve transposition for those athletes with clinically significant ulnar nerve instability.[72]

Several modifications of the Jobe original 3-ply technique have been developed over the past decade.[73] In addition, a variety of graft fixation methods have been investigated in both the clinical and laboratory settings. These include interference screws, suture anchors, flip-buttons, and combinations of these fixation methods, along with variations in tunnel placement both proximally and distally.[73–87] An arthroscopically assisted technique has been studied in the laboratory and has shown biomechanically promising results.[85]

The most widely applied and studied of these newer techniques is the docking procedure.[74,76,77,83,84,86,88,89] In the docking technique,

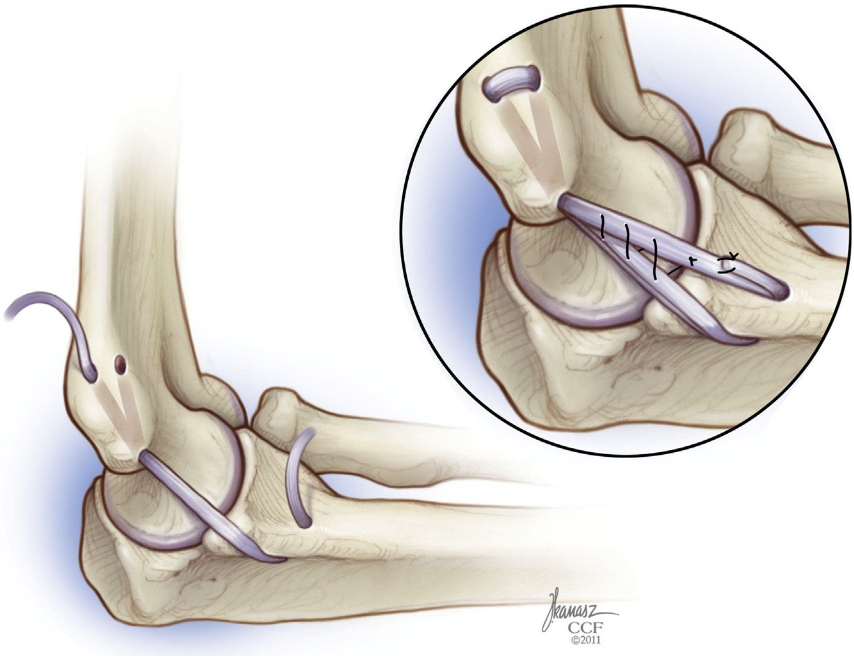

Fig. 7. Illustration of classic 3-ply medial UCL reconstruction technique as described by Jobe. Inset: Completed reconstruction. (*Courtesy of* Clinic Center for Medical Art & Photography © 2014, Cleveland. All Rights Reserved; with permission.)

converging drill holes are used to create a tunnel at the level of the sublime tubercle of the proximal ulna as in the Jobe 3-ply method. Instead of divergent tunnels in the medial epicondyle of the humerus, however, a single blind-ended tunnel (socket) is created (**Fig. 8**). At the end of this socket, 2 small exit holes are created to allow for passage of sutures that have been sutured to end of the graft. These sutures are used to pull the graft into the humeral socket where it is seated at the base. The passing sutures are then tied to each other over the back of the epicondyle. This method of fixation eliminates the suture/graft interface that is present in the 3-ply reconstruction and has been shown in biomechanical studies to have higher peak load to failure values compared with Jobe and interference screw techniques.[74,83] A recent systematic review by Watson and colleagues[90] found that the docking technique and a suspensory button technique most commonly failed secondary to suture failure, whereas the most common modes of failure for the Jobe technique and interference screw technique were ulnar tunnel fractures and graft ruptures, respectively.

A modification of the docking technique has recently been introduced. The DANE TJ UCL reconstruction uses traditional docking fixation proximally into a socket within the medial epicondyle of the humerus.[82,91] Distally, however, instead of a tunnel in the ulna, another socket is created (**Fig. 9**). Fixation of the ulnar end of the graft is achieved with an interference screw, whereas fixation proximally is performed with 2 sutures exiting the end of the humeral socket and tied to each other, as in the traditional docking technique. To augment proximal fixation of the graft, some surgeons place an interference screw within the medial epicondyle socket. The addition of an interference screw for fixation proximally has been shown to result in less gap formation under valgus loading in the laboratory setting, perhaps allowing for better healing of the graft within the humeral bone socket.[78–80] Aperture fixation, as is achieved with interference screws, may also result in increased graft isometry and increased stiffness of the overall construct.[75] Concerns with this type of fixation include low initial fixation strength and the potential for graft slippage in the early postoperative period.[78]

Surgical reconstruction of the UCL dictates a reduced pace of rehabilitation and is a lengthy process. Therefore, the postoperative management varies depending on the surgical procedure performed. The initial goals of the program center on protection of the UCL graft, decreasing pain and effusion, and maintaining muscular strength in the forearm-based musculature.

Patients are fit postoperatively with a posteriorly based elbow splint fixed at 90° of flexion for immobilization and a compression dressing during the

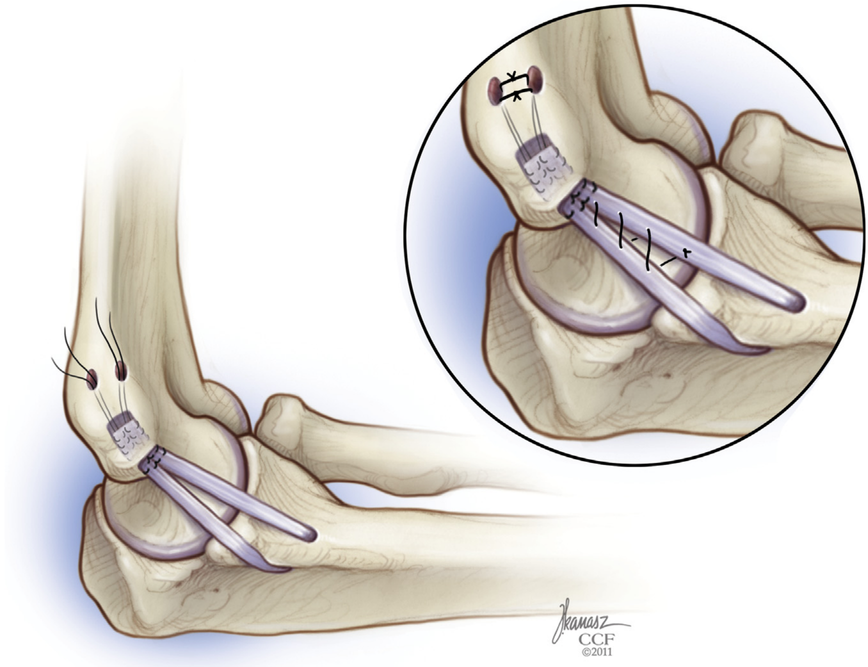

Fig. 8. Schematic of original docking technique for UCL reconstruction. Inset: Completed reconstruction. (*Courtesy of* Clinic Center for Medical Art & Photography © 2014, Cleveland. All Rights Reserved; with permission.)

acute phase of healing. During the immediate postoperative, acute phase of healing, the athlete is started on a program emphasizing wrist flexion and extension active ROM gripping exercises, while maintaining a neutral wrist position, and submaximal isometric exercises for the hand, wrist, and elbow in all directions. The initiation of the subacute phase of rehabilitation, usually 2 to

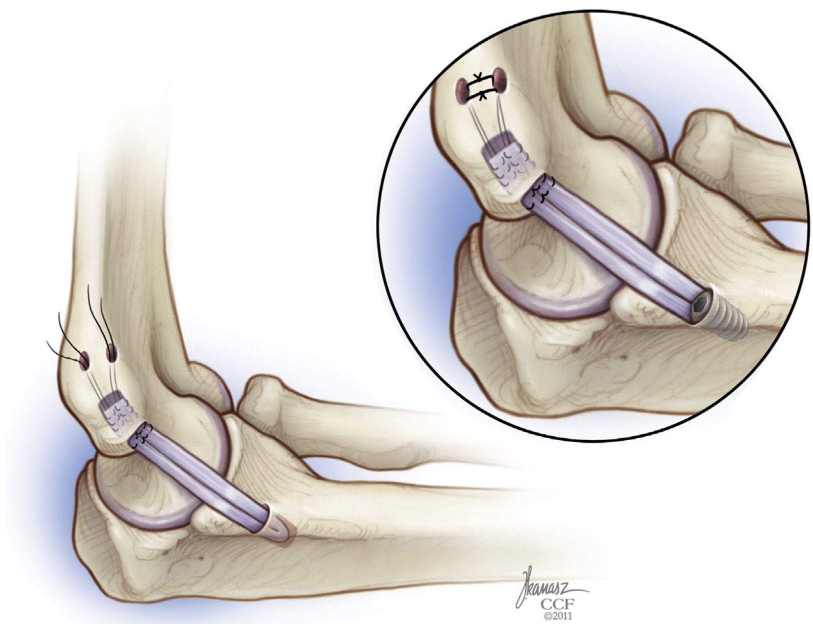

Fig. 9. Drawing of the DANE TJ modification of the docking technique. Inset: Completed reconstruction. (*Courtesy of* Clinic Center for Medical Art & Photography © 2014, Cleveland. All Rights Reserved; with permission.)

4 weeks, occurs as patients are transferred from the posterior splint to a hinged elbow brace that allows between 40° and 100° of elbow motion. The ROM is gradually increased so that full elbow ROM is achieved by postoperative week 5 to 6, at which time the hinged elbow brace usage is discontinued. Isometric exercise progression is advanced to include moderately applied force and light resistance isotonic exercises. Initiating the isotonic exercises while maintaining decreased valgus load allows for maximum support of the elbow as a new exercise procedure is introduced into the rehabilitation program. The athlete is advanced in the scapular stabilization and shoulder exercise program to include light to moderate resistance below 90° of shoulder elevation. Manual resistance is used for scapular stabilization exercises and short arc proprioceptive neuromuscular facilitation upper extremity patterns are initiated with resistance placed proximal to the elbow.

During the intermediate phase of rehabilitation, 6 to 10 weeks, the exercise program is advanced to include shoulder positioning into external rotation coupled with scapular retraction, shoulder elevation greater than 90°, biceps and triceps isotonic resistance, wrist pronation and supination, and core stabilization. Eccentric loading is initiated manually between 9 and 10 weeks postoperatively. Emphasis is placed on exercises that activate the FCU and flexor digitorum superficialis because they are believed to assist the UCL in medial elbow stabilization. Plyometric exercises are initiated after successful performance of manual and active resisted eccentric loading exercises. The athlete couples the exercise progression with nonthrowing baseball pitching–specific drills for balance point position, arm path to shoulder/elbow 90/90 positioning, and stride direction and length. The shoulder rotator cuff and scapulothoracic exercises incorporate functional chain positioning of the lower extremity and trunk to maximize complex movement patterns necessary for a successful return to throwing. A return-to-throw progression and interval throwing program is initiated at week 16.

Outcomes after UCL reconstruction have shown generally favorable results, with reported return-to-play rates as high as 95%.[38,45,64,67,72,77,84,88,89,91,92] A systematic review of the literature by Vitale and Ahmad[93] concluded that overall 83% of patients (493) had excellent results (return to the same level of play for at least 1 year). An overall complication rate of 10% is reported, with ulnar nerve complications the most common. Better results were seen with a muscle-splitting surgical approach, no ulnar nerve transposition, and utilization of the docking technique. Also, adolescent athletes do not fare as well as college and professional athletes after surgical reconstruction of the UCL. In a retrospective study of 27 high school athletes who had undergone UCL reconstruction, Petty and colleagues[94] reported that only 74% were able to return to the same level of play after surgery. They identified grossly positive stress radiographs, sublime tubercle avulsion fractures, and ossicles within the proximal end of the ligament as poor prognostic indicators.

In a more recent systematic review of more than 1300 patients, Watson and colleagues[90] found the docking technique demonstrated a lower complication rate (6.0%) compared with the Jobe technique (51.4%) ($P = 4.48 \times 10^{-6}$). Additionally, there was a trend toward a greater rate of return to play with the docking technique compared with the Jobe technique at 90.4% and 66.7%, respectively ($P = 1.29 \times 10^{-5}$).

Revision surgery for the treatment of failed reconstructed ligaments is technically challenging and is associated with a high incidence of complications and generally poor outcomes.[95,96] In a recent case series, Dines and colleagues[96] reported that only 33% of athletes were able to return to play after revision medial UCL reconstruction, with 40% of patients experiencing complications.

ULNAR NEUROPATHY

Ulnar neuropathy at the elbow is the second most prominent neuropathy of the upper extremity, and its superficial location makes it particularly susceptible to injury in throwing athletes. The ulnar nerve is susceptible to several mechanical factors, including compression, traction, and irritation of the nerve.[44] During the acceleration phase of the throwing motion, the ulnar nerve is subject to longitudinal traction.[97] Potential sites of compression proximal to the cubital tunnel include the arcade of Struthers and the medial intermuscular septum. Distal sites of potential compression include the area between the FCU and the medial forearm musculature. Recently, Li and colleagues[98] even reported compression through the anconeus epitrochlearis, which may be hypertrophied in overhead throwing athletes. Aoki and colleagues[99] found a hypertrophic medial head of the triceps impinging on the ulnar nerve as the elbow was flexed greater than 90° in a series of adolescent baseball players with ulnar neuropathy. Osborne ligaments represent the predominant compression site in the cubital tunnel, which is bordered laterally by the elbow, anteriorly by the medial epicondyle, and medially by the origin of the FCU,[100,101] although compression may also occur from osteophytes, loose bodies, or synovitis.

Repetitive throwing motions can cause both physiologic and pathologic responses that may be the primary cause of ulnar neuropathy.[102,103] Many secondary causes exist. More than 40% of athletes with valgus instability experience ulnar neuritis secondary to irritation from the inflammation of the UCL as well as increased stretch from valgus stress. Approximately 60% of athletes with medial epicondylitis develop ulnar nerve symptoms.[38,44,104] Osteophytes from valgus extension overload and friction from ulnar nerve subluxation can serve as underlying etiologies as well.[105]

Intraneural pressure within the ulnar nerve varies with wrist, elbow, and shoulder position. Pechan and Julis[106] found the pressure within the nerve to be 3 times the resting level when the elbow was flexed and the wrist extended. Continuation of the throwing motion with further elbow flexion and shoulder abduction causes the intraneural pressure to rise 6 times the resting level. This increased pressure is attributed to nerve stretch, tightening of the cubital tunnel, and compression.[107] Repetitive motions can induce chronic changes to the ulnar nerve and surrounding soft tissues, potentially leading to nerve fibrosis and ischemia.

In addition to the history and examination discussed previously, the elbow flexion test with the elbow maintained in maximum flexion and wrist in extension for 1 minute should be conducted. Symptoms of ulnar neuritis consist of an aching pain along the ulnar side of the forearm radiating into the ulnar 2 digits of the hand. Reports of clumsiness or numbness should be evaluated further. Monofilament testing can detect early sensory changes, and hand intrinsic atrophy or weakness represents the earliest motor changes.

Electrodiagnostic testing may be useful in diagnosing ulnar neuropathy; however, changes may not be seen until disease has advanced. Wei and colleagues[108] performed nerve conduction velocity testing in baseball pitchers and did not find a significant difference between the dominant and nondominant arms among injured pitchers. A negative electrodiagnostic test, however, does not rule out ulnar neuritis.[41,102]

Nonoperative Treatment

Nonoperative management typically begins with activity restriction, antiinflammatories, cryotherapy, and physical therapy. Ulnar subluxation or dislocation may require a brief period of immobilization. After resolution of symptoms, a gradual return-to-throw program can be initiated. Symptoms from superficial irritation of the nerve can be treated with elbow pads. Ulnar neuropathy in overhead throwing athletes typically stems, however, from an underlying cause, and as throwing is resumed, symptoms likely resurface.

Operative Treatment

Indications for operative management include failed nonoperative treatment, persistent ulnar-nerve subluxation, symptomatic tension neuropraxia, and concomitant medial elbow problems that require surgery.[107] The surgical options for treatment include decompression (in situ) of the ulnar nerve, medial epicondilectomy, and anterior transposition of the nerve (submuscular, intramuscular, or subcutaneous). Simple decompression and medial epicondilectomy are prone to failure in overhead throwing athletes. Decompression may address some of the compressive forces within and around the cubital tunnel but does not address irritation from traction and repetitive motion. Furthermore, in cases of ulnar nerve subluxation, decompression fails to stabilize the nerve. Medial epicondilectomy aims to prevent traction irritation to the nerve as it passes posterior to the medial epicondyle. Well-recognized complications include, however, nerve instability, valgus instability from iatrogenic injury to the UCL, and weakness from disruption of the flexor-pronator mass.

Anterior transposition of the ulnar nerve is the mainstay of surgical management of ulnar neuritis. Subcutaneous transposition has the advantage of less surgical morbidity to the flexor-pronator mass and may be recommended in patients undergoing concomitant UCL reconstruction.[45,109,110] The main disadvantage of the subcutaneous technique is its susceptibility to direct trauma.[44,102,103] Other concerns include potential for developing instability and recurrence of symptoms from new compression under the subcutaneous fasciodermal sling. Anterior submuscular transposition involves greater surgical dissection in the medial soft tissues and a lengthier postoperative rehabilitation course but provides thorough decompression of the nerve while protecting it from direct and indirect trauma. In submuscular transfer, the nerve sits deep to the medial flexor mass and arises superficial to the pronator muscle mass. The outcomes of ulnar nerve transposition in overhead athletes support both approaches in throwing athletes. Studies comparing the results of these techniques, including 2 meta-analyses, have not found a significant difference between the procedures in terms of postoperative clinical outcomes or motor nerve conduction velocities; however, these were not specific to throwing athletes.[111,112]

Del Pizzo and colleagues[41] reported their findings on 19 baseball players who underwent anterior subcutaneous ulnar nerve transposition for recalcitrant ulnar neuritis; 9 of 15 athletes (60%) evaluated at 3 to 58 months postoperatively were able to return to play. Rettig and Ebben[110] performed 21 anterior subcutaneous transposition procedures in 20 athletes for failed conservative management of cubital tunnel syndrome. All athletes returned to play at an average of 12.6 weeks. The investigators recommended subcutaneous transposition in light of faster postoperative recovery and rehabilitation.

The senior authors' (SMG and MSS) preference is subcutaneous anterior transposition of the ulnar nerve supported by facial slings, paying particular care to preserve the motor branches to the FCU. A 4- to 6-cm curvilinear incision is made just posterior to the medial epicondyle along the path of the ulnar nerve. Dissection is carried out, taking care to protect any branches of the medial antebrachial cutaneous nerve. The ulnar nerve is identified in the cubital tunnel by opening the cubital tunnel at its midsection just posterior to the medial epicondyle. The distal one-half of the cubital tunnel is then released, including the Osborne ligament and any compressive fibers in the proximal FCU. The proximal cubital tunnel is then released, extending proximally to the arcade of Struthers. Two fascial slings are developed from the superficial flexor-pronator muscle fascia, and the fascia is closed. The ulnar nerve is transposed anterior to the medial epicondyle and held loosely in place by suturing the fascial slings to the flexor fascia. The posterior triceps fascia is then sutured to the medial epicondyle to close the cubital tunnel, and the FCU fascial split is reapproximated loosely. The elbow is splinted in 90° of elbow flexion for the 7 to 10 days postoperatively to allow soft tissue healing, followed by progressive motion and rehabilitation to return to play.

FLEXOR-PRONATOR INJURY

The flexor-pronator muscle mass at the medial side of the elbow provides dynamic stability against valgus forces.[13–16] Repetitive contraction of the flexor-pronator muscles occurs during the acceleration phase of throwing as well as with wrist flexion during ball release.[16] An acute complete rupture of the common flexor-pronator origin from the medial epicondyle is an uncommon injury in overhead athletes; rather, athletes may develop a spectrum of injuries from mild muscular overuse to chronic tendinitis or acute partial muscle tears (**Fig. 10**).[65] The typical presentation includes an athlete with medial elbow pain during the late cocking or acceleration phase of throwing with continuation during ball release as the forearm is pronated and the wrist flexed. With complete ruptures of the flexor-pronator muscle mass, players may recall general prodromal symptoms followed by a single event leading to a pop sensation or sound.

The main differential diagnosis in these cases should include injury to the UCL. In flexor-pronator injuries, athletes have tenderness to palpation just distal to the medial epicondyle along the common origin. Meanwhile, in UCL injuries, the tenderness is typically posterior and distal to that of flexor-pronator pain along the sublime tubercle. Lastly, pain with flexor-pronator injury should be exacerbated with wrist flexion and elbow extension. Nevertheless, clinical differentiation between these 2 entities can be difficult and an MRI aids in diagnosis. Combined UCL and flexor-pronator injuries are not uncommon.

Overuse tendonitis and partial tears of the flexor-pronator muscle mass can be treated with active rest, ice, antiinflammatory medications, physical therapy, and gradual return to throwing. Corticosteroids are generally avoided given the proximity of the UCL. No data are currently available on the efficacy of PRP injections for flexor-pronator injury in overhead throwing athletes. Complete ruptures of the flexor-pronator origin require prolonged rest and rehabilitation. Splinting the wrist in neutral position may alleviate acute

Fig. 10. Coronal slice of an MRI of a minor league reliever demonstrating a tear of the flexor-pronator mass near the proximal origin (*circle*).

pain during the first 7 to 10 days after injury. Rehabilitation with emphasis on ROM first followed by resistance training is necessary before interval throwing is initiated. If pain or weakness reoccurs with throwing, then surgical repair may be necessary. Because surgical treatment is rarely required, failure of nonoperative treatment should heighten awareness of other underlying pathology.

Overhead throwers are also vulnerable to pronator syndrome, which is compression of the median nerve caused by hypertrophy of pronator teres secondary to repetitive activity. Athletes complain of vague, fatigue-like pain over the proximal volar aspect of forearm exacerbated by resisted forearm pronation and wrist flexion. If nonoperative management with activity modification and antiinflammatory medications fails, then surgical exploration with division of superficial head of the pronator teres and decompression of the median nerve may be required. Similarly, hypertrophy of the flexor-pronator mass can cause a localized compartment syndrome induced by repetitive throwing. Medial elbow and forearm pain is associated specifically with throwing and resolves with rest. This condition may be difficult to diagnose but typically responds well to adequate stretching, interval rests, and adherence to proper pitching mechanics.[3]

MEDIAL EPICONDYLE AVULSION OR APOPHYSITIS

Little League elbow is a general term referring to medial-sided stress injuries that can occur in skeletally immature throwing athletes.[113,114] Medial epicondyle avulsion injury and apophysitis are the most common injuries and are prevalent in youth baseball. Hang and colleagues[29] found that 52% of Little League players in Taiwan reported medial elbow pain or soreness at some point during the course of a season. Grana and Rashkin[115] reported that 58% of older adolescent pitchers experience elbow pain or injury at some point during the season. In skeletally immature throwers, both the static (UCL) and dynamic (flexor-pronator muscle group) medial stabilizers attach to the medial epicondyle, thus conferring all of the static and dynamic stress to the medial epicondylar physis. Valgus and contractile forces across the elbow that result in ligament and tendon injury in the adult thrower lead to injury to the weaker medial epicondyle apophyseal plate in the skeletally immature thrower. Symptomatic injury is associated with the combination of repetitive forces on the medial elbow and inadequate intervals of rest.[116–118] The use of breaking pitches in this age group and improper throwing mechanics have also been suggested as possible causes but not proved.[117–119] Bennett coined the term, Little Leaguer's elbow, to describe the clinical and radiographic changes associated with these medial-sided traction injuries in skeletally immature athletes.[120] Repetitive valgus loading can lead to apophyseal fragmentation or avulsion of the medial epicondyle apophysis as well as changes in the radiocapitellar joint laterally.

Medial epicondylar apophysitis should be suspected in young athletes with point tenderness over the medial epicondyle and pain with valgus stress of the elbow. Patients with avulsion fractures typically have significant swelling and decreased ROM. Radiographs may show a subtle widening of the physeal plate and comparison views of the uninvolved limb are vital. MRI typically shows more findings than radiographs; however, these do not necessarily have clinical correlation and do not change management.[121]

Initial treatment consists of an extended period of rest and cryotherapy until symptoms resolve and a gradual return to throwing. Harada and colleagues[122] found that athletes noncompliant with pitching restrictions and who returned to rigorous activity prior to bone union on radiographs had significant delays in bone union at both 6 months and 1 year compared with athletes who waited until complete bone union prior to resuming rigorous throwing. Although activity modification is successful in apophysitis, treatments of epicondylar avulsions remain controversial.[123]

In cases of complete avulsion of the medial epicondyle, most investigators recommend open reduction and internal fixation if the fragment is displaced 5 mm or greater. Nonoperative management is successful in the management of minimally displaced fractures without instability. These injuries can be treated with splint immobilization for 5 to 7 days, followed by early motion.[124–126] Lawrence and colleagues[127] recommend nonoperative management in young athletes with low-energy medial epicondyle avulsions, a stable elbow, and minimal fracture displacement (5.3 ± 2.0 mm). Open reduction and internal fixation can be successful in athletes who sustain more significant trauma, who have elbow laxity or instability, or who have significant fracture fragment displacement (7.1 ± 2.9 mm) after a fracture of the medial epicondyle.

VALGUS EXTENSION OVERLOAD SYNDROME

Valgus extension overload can occur with an attenuated UCL or in a physiologic lax elbow with repetitive valgus stress from throwing. Athletes most commonly complain of posteromedial elbow pain during the extension (late acceleration) or follow-through phase of throwing.[128] During these phases, the elbow subluxates and increases force in the lateral and posterior compartments. Continued compressive and rotatory forces in the lateral compartment lead to synovitis and osteochondrosis of the radiocapitellar joint.[3,36] Posterior and posteromedial olecranon osteophytes that form from impingement may fracture and contribute to loose bodies along with osteochondral fragments from the radiocapitellar joint (**Fig. 11**). When athletes complain of locking or catching, loose bodies should be considered. Radiographs may demonstrate osteophytes or loose bodies. Cohen and colleagues[129] have found a typical pattern of valgus extension overload syndrome on MRI findings. All 9 throwing athletes had pathology at the articular surfaces of the posterior trochlea and the anterior, medial olecranon. The investigators also found that these MRI findings correlated with arthroscopic findings.

Nonoperative Treatment

Initial treatment should consist of active rest with cryotherapy, iontophoresis, and antiinflammatory medications to relieve pain. As symptoms subside and motion returns to baseline, rehabilitation should include dynamic stabilization and strengthening exercises with emphasis on eccentric strengthening of the elbow flexors to control rapid extension of the elbow. Manual resistance exercises of concentric and eccentric elbow flexion are performed prior to an interval throwing program.[130]

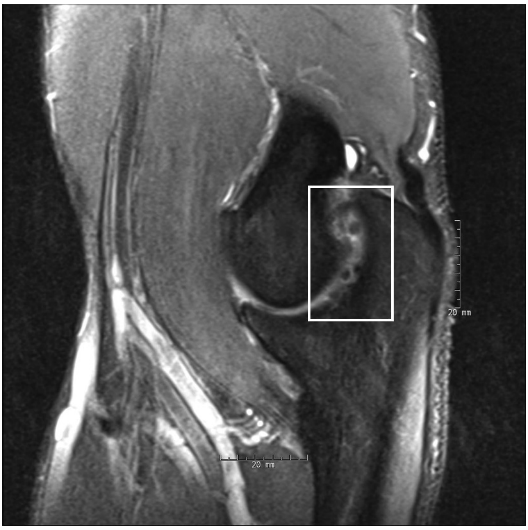

Fig. 11. Sagittal cut of an MRI of an overhead throwing athlete demonstrating multiple irregularities of the posterior articular surface of the olecranon (*square*).

Operative Treatment

Andrews and Timmerman[69] reported posteromedial olecranon impingement the most common diagnosis requiring surgery in baseball players (78%). Failure of nonoperative management for impingement-related pain is a surgical indication. Nonoperative treatment is deferred in overhead athletes with symptomatic posterior medial osteophytes or loose bodies. The treatment of choice in these instances is débridement and removal of the loose bodies. Arthroscopic treatment has become the mainstay of olecranon débridement and excision of loose bodies.[36,131] Arthroscopic evaluation also allows for débridement or drilling of osteochondral defects, resection of hypertropic synovium, and inspection for undersurface tears of the UCL.[132] Athletes must understand the risk of recurrence with continued throwing as well as risk of damage to the ulnar nerve with this technique.[69]

Reddy and colleagues[133] reported 187 arthroscopies done in 172 patients at the Kerlan-Jobe Orthopaedic Clinic. The most common diagnosis was posterior impingement (51%), followed by loose bodies (31%) and degenerative joint disease (22%). Laxity of the UCL was seen in 6% of cases. Although 68 patients were lost to follow-up, they reported 49% excellent, 36% good, 11% average, and 4% poor results, based on the modified Figgie score; 47 of the 55 professional athletes (85%) returned to their previous level of competition. There were 3 transient complications, 1 related to the ulnar nerve. Andrews and Timmerman[69] evaluated 56 professional baseball players who underwent arthroscopic olecranon osteophyte excision either as an isolated procedure or with concomitant ulnar nerve transposition or UCL reconstruction; 23 of 34 patients (68%) available for minimum 24-month follow-up returned to play at least 1 season. However, 14 (41%) required reoperation, including repeat débridement of olecranon osteophytes (6) and UCL reconstruction (5). The investigators cautioned against excessive olecranon excision. Resection of more than 3 mm of the posteromedial olecranon jeopardizes the function of the anterior bundle of the UCL because it exposes a potentially attenuated UCL to higher stresses.[134,135] Thus, it is recommended that only the osteophyte and no native olecranon be removed.

OLECRANON STRESS FRACTURE

Proximal olecranon stress fractures occur from the repetitive microtrauma, excessive tensile stress from the triceps tendon, and posterior impingement of the olecranon against the olecranon fossa associated with competitive overhead throwing.[136] Stress fractures can have posterolateral or posteromedial olecranon pain and tenderness during and after throwing.[137] There is typically no pain at rest and there is a gradual onset rather than a single event. Schickendantz and colleagues[137] state pain with percussion of the proximal ulna may indicate a stress fracture because it was a positive test in all 7 athletes with MRI-confirmed stress reactions. Stress fractures of the proximal olecranon should be differentiated from avulsion fractures of the tip of the olecranon and from a persistent olecranon apophysis, which may be treated differently. Standard radiographs as well as advanced imaging may be needed for diagnosis.

Nonoperative Treatment

Initial treatment includes rest, immobilization, and throwing cessation. Specifically, any valgus stress should be avoided for a minimum of 6 weeks. Full extension should also be avoided with the use of a splint or orthosis set to approximately 20° of extension for the first 4 weeks. At 4 weeks, full ROM is allowed and progressive resistance exercises of the elbow are initiated. At 6 weeks, sport-specific rehabilitation is initiated and an interval throwing program typically starts at approximately 8 weeks. Nuber and Diment[138] successfully treated 2 olecranon stress fractures in competitive pitchers with splinting and cessation of throwing. Both players had radiographic union and returned to pitching.

Operative Treatment

Complete olecranon stress fractures in competitive throwers often require surgical treatment with cannulated screws or plate osteosynthesis. The goal of surgical fixation is compression and rigid fixation across the fracture site. Paci and colleagues[139] have published the only report on surgical fixation of proximal olecranon stress fractures in baseball players. They performed percutaneous fixation of the proximal ulna stress fracture in 25 baseball players and had follow-up on 18 of the athletes. All 18 fractures went on to union, with 17 of 18 (94%) athletes able to return to preinjury level of play.

OSTEOCHONDRITIS DISSECANS OF THE CAPITELLUM

The radiocapitellar joint experiences compressive forces during valgus stress from overhead throwing motions. Repetitive compressive trauma, in addition to ischemia and genetics, has been implicated in the formation of OCD of the capitellum. The exact cause, however, remains unclear. A wide spectrum of injuries can result, including subchondral changes to secondary osteochondrosis of the radial head to loose bodies. Treatment depends on the severity and stability of the osteochondral lesion. Patients often complain of lateral elbow pain on palpation and valgus stress. There is frequently an associated loss of elbow extension, ranging from 5° to 20°. Athletes may also have swelling or effusion, tenderness over the lateral aspect of the elbow, and crepitance with motion.[140] Standard radiographs demonstrate classic findings of a subchondral cyst of the capitellum in early cases. In more advanced stages, flattening and irregularity of the capitellar articular surface may be seen.

Mihata and colleagues[141] performed a biomechanical cadaveric study and found that OCDs of the radiocapitellar joint increase elbow valgus laxity and contact pressure without increasing UCL strain. Natural history suggests that as many as 50% of patients experience some degeneration in the radiocapitellar joint.[142]

Nonoperative Treatment

Nonoperative management should be reserved for early lesions and consists of a minimum 6-week period of rest from throwing and valgus stress.[143] After pain resolves, a strengthening program is initiated with isometric exercises, followed by isotonic exercises. Aggressive high-speed, eccentric, and plyometric exercises are progressively included to prepare athletes for the start of an interval throwing program. Mihara and colleagues[144] reported on 39 baseball players with a mean age of 12.8 years with OCD lesions of the capitellum treated nonoperatively. At a mean follow-up of 14.4 months, 25 of 30 early lesions were healed compared with 1 of 9 advanced lesions. A majority of the lesions in patients with open physes healed (16 of 17) compared with only 11 of 22 patients with closed physes.

Operative Treatment

Surgical intervention is limited to patients who do not respond to a nonoperative course of treatment or those with advanced disease resulting in the development of loose fragments within the joint. Initially, surgical management consisted of open débridement and fragment excision. Bauer and colleagues[145] reported long-term outcomes in 31 patients with a mean age of 20 years. Of these patients, 22 had loose body excision and 1 had radial head excision, and most cases seemed to be advanced lesions (20 of 31). At average 23-year follow-up, there was a 40% recurrence of symptoms and loss of elbow extension, with greater than 60% of examined radiocapitellar joints demonstrating degenerative joint disease. In an initial study, Takahara and colleagues[142] reported 39 patients with an average age of 17.6 years treated with open fragment excision. At average 14.7 years' follow-up, 26% of patients reported good results, and 49% returned to full sports participation. Takahara and colleagues[146] followed their initial study with another study adding 16 patients to their original cohort. The investigators added that better results in terms of pain and radiographic findings were seen in patients with lesions measuring less than 50% of the capitellar articular width.

Arthroscopic débridement and abrasion chondroplasty have had promising results in numerous short and midterm follow-up studies, with pain relief and objective improvements in elbow ROM.[140,147–150] Byrd and Jones[148] examined 10 patients ages 11 to 16 years, 7 with advanced disease (grade IV or V lesions based on the American Sports Medicine Institute classification system of OCD lesions). At 4-year follow-up, although all 7 lesions healed, only 4 of 10 patients had returned to sport, and 2 demonstrated degenerative radiographic findings. The investigators found no correlation between grade of lesion and postoperative outcomes or return to sport. Ruch and colleagues[151] treated 12 patients, ages 11 to 17 years, with unstable elbow lesions (mean size 2.5 cm) for a mean of 3.2 years. Improved extension was seen postoperatively, mechanical symptoms resolved in 11 patients, and 11 of 12 patients were highly satisfied. Radiographs demonstrated capitellar remodeling in all elbows. Only 3 patients, however, returned to sport.

Fragment fixation has been attempted through a variety of techniques and implants.[146,152–155] Reliable results have been seen in advanced cases, but published data have been limited to small case series. Lateral closing wedge osteotomy has been used to unload the radiocapitellar joint. The procedure is technically challenging because ulnohumeral joint alignment must be maintained. Because the lesion is not directly addressed, this procedure is reserved for early lesions that are stable. Kiyoshige and colleagues[156] evaluated 7 baseball players ages 11 to 18 who underwent a lateral closing wedge osteotomy. At 7- to 12-year follow-up, 6 of 7 patients (86%) had complete relief of pain with return to sport.

Osteochondral autograft transplantation (OAT) is another technique to treat advanced OCD lesions of the capitellum. Contraindications include degenerative changes in the radiocapitellar compartment and radial head and capitellar deformity. Placement of grafts in the tight lateral compartment make congruent placement of the graft difficult.[157] Early results demonstrate reasonable outcomes with OAT but long-term follow-up in the throwing population is needed before definitive conclusions can be drawn.[158,159]

SUMMARY

Overhead throwing activities expose the elbow to tremendous valgus stress, making athletes vulnerable to a specific constellation of injuries. Although baseball players, in particular pitchers, are the athletes most commonly affected, overhead athletes in football, volleyball, tennis, and javelin throwing also are affected.

Increasing participation in overhead throwing sports has led to a sharp increase in injuries. Understanding the anatomy and function of the elbow, along with the biomechanical relationship between the two, remains vital to appropriate management. Advances in surgical technique to reconstruct the UCL have led to improved outcomes while multiple fixation devices and grafts have been evaluated.

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