21

Rehabilitation of the Elbow

Todd S. Ellenbecker, Tad Pieczynski, and David Carfagno

OBJECTIVES

After completing this chapter, the therapist should be able to do the following:

- > Discuss the functional anatomy and biomechanics associated with normal function of the elbow.
- Identify the various techniques for regaining range of motion including stretching exercises and joint mobilizations.
- Perform specific clinical tests to identify ligamentous laxity and tendon pathology in the injured elbow.
- Discuss criteria for progression of the rehabilitation program for different elbow injuries.
- Demonstrate the various rehabilitative strengthening techniques for the elbow, including openand closed-kinetic chain isometric, isotonic, plyometric, isokinetic, and functional exercises.

Treatment of elbow injuries in active individuals requires an understanding of the mechanism of injury and the anatomy and biomechanics of the human elbow and upperextremity kinetic chain, as well as a structured and detailed clinical examination to identify the structure or structures involved. Treatment of the injured elbow of both a younger adolescent patient and an older active patient requires this same approach. This approach consists of understanding the specific anatomical vulnerabilities present in the young athletes' elbow, as well as the effects of years of repetitive stress and the clinical ramifications these stresses produce in the aging elbow joint. An overview of the most common elbow injuries, as well as a review of the musculoskeletal adaptations of the elbow, will provide a platform for the discussion of examination and most specifically treatment concepts for patients with elbow injury. The important interplay between the elbow and shoulder joints in the upperextremity kinetic chain is highlighted throughout this chapter in order to support comprehensive examination and intervention strategies, as well as the total-arm strength treatment concept.

Functional Anatomy and Biomechanics

Anatomically, the elbow joint comprises 3 joints. The humeroulnar joint, humeroradial joint, and the proximal radioulnar joint are the articulations that make up the elbow complex (Figure 21-1). The elbow allows for flexion, extension, pronation, and supination movement patterns about the joint complex. The bony limitations, ligamentous support, and muscular stability help to protect it from vulnerability of overuse and resultant injury.

The elbow complex comprises 3 bones: the distal humerus, proximal ulna, and proximal radius. The articulations among these 3 bones dictate elbow movement patterns.¹²⁵ It is also important to mention that the appropriate strength and function of the upper quarter (defined as the cervical spine to the hand, including the scapulothoracic joint) need to be addressed when evaluating the elbow specifically. The elbow complex has an intricate mechanical articulation between the 3 separate joints of the upper quarter in order to allow for function.



Figure 21-1 Articulations of the elbow joint complex



Figure 21-2

A. Elbow joint capsule. B. Medial ulnar collateral ligament complex.

In the elbow, the joint capsule plays an important role. The capsule is continuous (Figure 21-2A) among the 3 articulations and highly innervated.^{87,92} This is important not only for support of the elbow joint complex but also for proprioception of the joint. The capsule of the elbow functions as a neurologic link between the shoulder and the hand within the upper-extremity kinetic chain. Therefore, function of the capsule has an effect on upper-quarter activity and is an obvious important consideration during the rehabilitation process, if injury does occur.

Humeroulnar Joint

The humeroulnar joint is the articulation between the distal humerus medially and the proximal ulna. The humerus has distinct features distally. The medial aspect has the medial epicondyle and an hourglass-shaped trochlea, located anteromedial on the distal humerus.^{2,53} The trochlea extends more distal than the lateral aspect of the humerus. The trochlea articulates with the trochlear notch of the proximal ulna.

Because of the more distal projection of the humerus medially, the elbow complex demonstrates a carrying angle that is essentially an abducted position of the elbow in the anatomic position. The normal carrying angle (Figure 21-3) is 10 to 15 degrees in females and 5 degrees in males.⁷



Figure 21-3 Carrying angle of the human elbow

Radiocapitellar Joint (Humeroradial Joint)

The radiocapitellar or humeroradial joint is the articulation of the distal lateral humerus and the proximal radius. The lateral aspect of the humerus has the lateral epicondyle and the capitellum, which is located anterolateral on the distal humerus. With flexion, the radius is in contact with the radial fossa of the distal humerus, whereas in extension, the radius and the humerus are not in contact.

Proximal Radioulnar Joint

The proximal radioulnar joint is the articulation between the radial notch of the proximal lateral aspect of the ulna, the radial head, and the capitellum of the distal humerus. The proximal and distal radioulnar joints are important for supination and pronation. Proximally, the radius articulates with the ulna by the support of the annular ligament, which attaches to the ulnar notch anteriorly and posteriorly. This ligament circles the radial head and adds support. The interosseous membrane is the connective tissue that functions to complete the interval between the 2 bones. When there is a fall on the outstretched arm, the interosseous membrane can shift forces off the radius-the main weightbearing bone of the forearm-to the ulna. This prevents the radial head from having force-

ful contact with the capitellum. Distally, the concave radius articulates with the convex ulna. With supination and pronation, the radius moves on the more stationary ulna.

Ligamentous Structures

The stability of the elbow starts with the joint capsule and excellent bony congruity inherent to the three articulations of the human elbow. The capsule is loose anteriorly and posteriorly to allow for movement in flexion and extension.¹³¹ The joint capsule is taut medially and laterally as a result of the added support of the collateral ligaments.

The medial (ulnar) collateral ligament (MUCL) is fan shaped in nature and has 3 bands (see Figure 21-2B). The anterior band of the MUCL is the primary stabilizer of the elbow against valgus loads when the elbow is near extension.¹³¹ The posterior band of the MUCL becomes taut after 60 degrees of elbow flexion and assists in stabilizing against valgus stress when the elbow is in a flexed position. The oblique band of the MUCL does not technically cross the elbow joint and this does not provide extensive stabilization to the medial elbow like the anterior and posterior bands.

The lateral elbow complex consists of 4 structures. The radial collateral ligament attachments are from the lateral epicondyle to the annular ligament. The lateral ulnar collateral ligament is the primary lateral stabilizer and passes over the annular ligament into the supinator tubercle. It reinforces the elbow laterally, as well as re-enforcing the humeroradial joint.^{103,131} The accessory lateral collateral ligament passes from the supinator tubercle into the annular ligament. The annular ligament is the main support of the radial head in the radial notch of the ulna. The interosseous membrane is a syndesmotic tissue that connects the ulna and the radius in the forearm.

Dynamic Stabilizers of the Elbow Complex

The elbow flexors are the biceps brachii, brachialis, and brachioradialis muscles (Figure 21-4). The biceps brachii originates via 2 heads proximally at the shoulder: the long head from the supraglenoid tuberosity of the scapula, and the short head from the coracoid process of the scapula. The insertion is achieved by a common tendon at the radial tuberosity and lacertus fibrosis to origins of the forearm flexors. The functions of the biceps brachii are flexion of the elbow and supination the forearm.¹³⁶ The brachialis originates from the lower two-thirds of the anterior humerus and inserts on the coronoid process and tuberosity of the ulna. It functions to flex the elbow. The brachioradialis, which originates from the lower two-thirds of the lateral humerus and attaches to the lateral styloid process of the distal radius, functions as an elbow flexor as well as a weak pronator and supinator of the forearm.

The elbow extensors are the triceps brachii and the anconeus muscles. The triceps brachii has long, medial, and lateral heads. The long head originates at the infraglenoid tuberosity of the scapula, the lateral and medial heads to the posterior aspect of the humerus. The insertion is via the common tendon posteriorly at the olecranon. Through this insertion along with the anconeus muscle that assists the triceps, extension of the elbow complex is accomplished.



Figure 21-4 Valgus stress test to evaluate the medial ulnar collateral ligament complex

Clinical Examination of the Elbow

Although it is beyond the scope of this chapter to describe a complete elbow examination, several important components necessary in the comprehensive examination of the athletes elbow are discussed. Structural inspection of the athletes elbow must include a complete and thorough inspection of the entire upper extremity and trunk, because of the reliance of the entire upper-extremity kinetic chain on the core for power generation and force attenuation during functional activities.³⁷ Adaptive changes are commonly encountered during clinical examination of the athletes, use of the contralateral extremity as a baseline is particularly important to determine the degree of actual adaptation that may be a contributing factor in the patient's injury presentation.

Anatomical adaptation of the athlete's elbow can be categorized into 4 main categories for the purpose of this chapter. These include range of motion (ROM), osseous, ligamentous, and muscular. Each is presented in the context of the clinical examination of the patient with elbow dysfunction.

Range of Motion Adaptations

King et al⁷⁷ initially reported on elbow ROM in professional baseball pitchers. Fifty percent of the pitchers they examined were found to have a flexion contracture of the dominant elbow with 30% of subjects demonstrating a cubitus valgus deformity. Chinn et al²¹ measured world-class professional adult tennis players and reported significant elbow flexion contractures on the dominant arm, but no presence of a cubitus valgus deformity.

More recently, Ellenbecker et al³⁸ measured elbow extension in a population of 40 healthy professional baseball pitchers and found flexion contractures averaging 5 degrees. Directly related to elbow function was wrist flexibility, which Ellenbecker et al³⁸ reported as significantly less in extension on the dominant arm because of tightness of the wrist flexor musculature, with no difference in wrist flexion ROM between extremities. Ellenbecker and Roetert⁴¹ measured senior tennis players age 55 years and older and found flexion contractures averaging 10 degrees in the dominant elbow, as well as significantly less wrist flexion ROM. The higher utilization of the wrist extensor musculature is likely the cause of limited wrist flexor ROM among the senior tennis players, as opposed to the reduced wrist extension ROM seen from excessive overuse of the wrist flexor muscles inherent in baseball pitching.^{47,112}

More proximally, measurement of ROM of humeral rotation in the older overhead athlete is also recommended. Several studies show consistent alterations of shoulder rotational ROM in the overhead athlete.^{42,75,114} Ellenbecker et al⁴² showed statistically greater dominant-shoulder external rotation and less internal rotation in a sample of professional baseball pitchers. Despite these differences in internal and external rotation ROM, the total rotation (internal rotation + external rotation) between extremities remained equal, such that any increases in external rotation ROM were matched by decreases in internal rotation ROM in this uninjured population. Elite level tennis players had significantly less internal rotation and no significant difference in external rotation on the dominant arm, and an overall decrease in total rotation ROM on the dominant arm of approximately 10 degrees. Careful monitoring of glenohumeral joint ROM is recommended for the athlete with an elbow injury.

Based on the findings of these descriptive profiles, the finding of an elbow flexion contracture and limited wrist flexion or extension ROM, as well as reduced glenohumeral joint internal rotation, can be expected during the examination of the older athlete who performs a unilateral upper-extremity sport. Careful measurement during the clinical examination is recommended to determine baseline levels of ROM loss in the distal upper extremity. This careful measurement serves to determine if rehabilitative interventions are needed as well as to assess progress during rehabilitation.

Osseous Adaptation

In a study by Priest et al,¹⁰⁸ 84 world-ranked tennis players were studied using radiography, and an average of 6.5 bony changes were found on the dominant elbow of each player. Additionally, they reported twice as many bony adaptations, such as spurs, on the medial aspect of the elbow as compared to the lateral aspect. The coronoid process of the ulna was the number 1 site of osseous adaptation or spurring. An average of 44% increase in thickness of the anterior humeral cortex was found on the dominant arm of these players, with an 11% increase in cortical thickness reported in the radius of the dominant tennis playing extremity.

Additionally, in an MRI study, Waslewski et al¹³⁷ found osteophytes at the proximal or distal insertion of the ulnar collateral ligament in 5 of 20 asymptomatic professional baseball pitchers, as well as posterior osteophytes in 2 of 20 pitchers.

Ligamentous Laxity

Manual clinical examination of the human elbow to assess medial and lateral laxity can be challenging, given the presence of humeral rotation and small increases in joint opening that often present with ulnar collateral ligament injury. Ellenbecker et al³⁸ measured medial elbow joint laxity in 40 asymptomatic professional baseball pitchers to determine if bilateral differences in medial elbow laxity exist in healthy pitchers with a long history of repetitive overuse to the medial aspect of the elbow. A Telos stress radiography device was used to assess medial elbow joint opening, using a standardized valgus stress of 15 daN (kPa) with the elbow placed in 25 degrees of elbow flexion and the forearm supinated. The joint space between the medial epicondyle and coronoid process of the ulna was measured using anterior-posterior radiographs by a musculoskeletal radiologist and compared bilaterally, with and without the application of the valgus stress. Results showed significant differences between extremities with stress application, with the dominant elbow opening 1.20 mm, and the nondominant elbow opening 0.88 mm. This difference, although statistically significant, averaged 0.32 mm between the dominant and nondominant elbow and would be virtually unidentifiable with manual assessment. Previous research by Rijke et al¹¹³ using stress radiography identified a critical level of 0.5-mm increase in medial elbow joint opening in elbows with ulnar collateral ligament injury. Thus, the results of the study by Ellenbecker et al³⁸ do support this 0.5-mm critical level, as asymptomatic professional pitchers in their study exhibited less than this 0.5 mm of medial elbow joint laxity.

Muscular Adaptations

Several methods can be used to measure upper-extremity strength in athletic populations. These can range from measuring grip strength with a grip strength dynamometer to the use of isokinetic dynamometers to measure specific joint motions and muscular parameters. Increased forearm circumference was measured on the dominant forearm in world-class tennis players,²¹ as well as in the dominant forearm of senior tennis players.⁸⁰

Isometric grip strength dynamometer measurements in elite adult and senior tennis players demonstrated unilateral increases in strength. Increases ranging from 10% to 30% have been reported using standardized measurement methods.^{21,34,37,80}

Isokinetic dynamometers have been used to measure specific muscular performance parameters in elite-level tennis players and baseball pitchers.^{34,37,39,40} Specific patterns of unilateral muscular development have been identified by reviewing the isokinetic literature from different populations of overhead athletes. Ellenbecker³⁴ measured isokinetic wrist

and forearm strength in mature adult tennis players who were highly skilled, and found 10% to 25% greater wrist flexion and extension as well as forearm pronation strength on the dominant extremity as compared to the non-dominant extremity. Additionally, no significant difference between extremities in forearm supination strength was measured. No significant difference between extremities was found in elbow flexion strength in elite tennis players, but dominant arm elbow extension strength was significantly stronger than the non-tennis-playing extremity.³⁹

Research on professional throwing athletes has identified significantly greater wrist flexion and forearm pronation strength on the dominant arm by as much as 15% to 35% when compared to the nondominant extremity,³⁷ with no difference in wrist extension strength or forearm supination strength between extremities. Wilk, Arrigo, and Andrews¹³⁹ reported 10% to 20% greater elbow flexion strength in professional baseball pitchers on the dominant arm, as well as 5% to 15% greater elbow extension strength as compared to the nondominant extremity.

These data help to portray the chronic muscular adaptations that can be present in the senior athlete who may present with elbow injury, as well as help to determine realistic and accurate discharge strength levels following rehabilitation. Failure to return the dominant extremity-stabilizing musculature to its preinjury status (10% to as much as 35% greater than the nondominant) in these athletes may represent an incomplete rehabilitation and prohibit the return to full activity.

Clinical Examination Methods

In addition to the examination methods outlined in the previous section, including accurate measurement of both distal and proximal joint ROM, radiographic screening, and muscular strength assessment, several other tests should be included in the comprehensive examination of the elbow of the older active patient. Although it is beyond the scope of this chapter to completely review all of the necessary tests, several are highlighted based on their overall importance. The reader is referred to Morrey⁹² and Ellenbecker and Mattalino³⁷ for more complete chapters solely on examination of the elbow.

Clinical testing of the joints proximal and distal to the elbow allows the examiner to rule out referred symptoms and ensure that elbow pain is from a local musculoskeletal origin. Overpressure of the cervical spine in the motions of flexion/extension and lateral flexion/ rotation, as well as quadrant or Spurling test combining extension with ipsilateral lateral flexion and rotation, are commonly used to clear the cervical spine and rule out radicular symptoms.⁵⁰

Additionally, clearing the glenohumeral joint, and determining whether concomitant impingement or instability is present, is also highly recommended.³⁷ Use of the sulcus sign⁸⁸ to determine the presence of multidirectional instability of the glenohumeral joint, along with the subluxation/relocation sign⁶⁷ and load and shift test, can provide valuable insight into the status of the glenohumeral joint. The impingement signs of Neer⁹⁴ and Hawkins and Kennedy⁵⁷ are also helpful to rule out proximal tendon pathology.

In addition to the clearing tests for the glenohumeral joint, full inspection of the scapulothoracic joint is recommended. Removal of the patient's shirt or examination of the patient in a gown with full exposure of the upper back is highly recommended. Kibler et al⁷⁶ has recently presented a classification system for scapular pathology. Careful observation of the patient at rest and with the hands placed upon the hips, as well as during active overhead movements, is recommended to identify prominence of particular borders of the scapula, as well as a lack of close association with the thoracic wall during movement.^{73,74} Bilateral comparison provides the primary basis for identifying scapular pathology; however, in many athletes, bilateral scapular pathology can be observed. The presence of overuse injuries in the elbow occurring with proximal injury to the shoulder complex or with scapulothoracic dysfunction is widely reported,^{33,37,92,95,96} and thus a thorough inspection of the proximal joint is extremely important in the comprehensive management of elbow pathology.

Elbow Joint: Special Tests

Several tests specific for the elbow should be performed to assist in the diagnosis of elbow dysfunction. These include the Tinel test, varus and valgus stress tests, the milking test, valgus extension overpressure test, bounce home test, and provocation tests. The Tinel test involves tapping of the ulnar nerve in the medial region of the elbow over the cubital tunnel retinaculum. Reproduction of paresthesia or tingling along the distal course of the ulnar nerve indicates irritability of the ulnar nerve.⁹²

The valgus stress test (see Figure 21-4) is used to evaluate the integrity of the ulnar collateral ligament. The position used for testing the anterior band of the ulnar collateral ligament is characterized by 15 to 25 degrees of elbow flexion and forearm supination. The elbow flexion position is used to unlock the olecranon from the olecranon fossa and decreases the stability provided by the osseous congruity of the joint. This places a greater relative stress on the medial ulnar collateral ligament.⁹³ Reproduction of medial elbow pain, in addition to unilateral increases in ulnohumeral joint laxity, indicates a positive test. Grading the test is typically performed using the American Academy of Orthopedic Surgeons guidelines of 0 to 5 mm grade I, 5 to 10 mm grade II, and greater than 10 mm grade III.³⁸ Performing the test using a position of greater than 25 degrees of elbow flexion will increase the amount of humeral rotation during performance of the valgus stress test and lead to misleading information to the clinician's hands. The test is typically performed with the shoulder in the scapular plane, but can be performed with the shoulder in the coronal plane, to minimize compensatory movements at the shoulder during testing. The milking sign is a test the patient performs on himself, with the elbow held in approximately 90 degrees of flexion. By reaching under the involved elbow with the contralateral extremity, the patient grasps the thumb of their injured extremity and pulls in a lateral direction, thus imposing a valgus stress to the flexed elbow. Some patients may not have enough flexibility to perform this maneuver, and a valgus stress can be imparted by the examiner to mimic this movement, which stresses the posterior band of the ulnar collateral ligament.⁹³

The varus stress test is performed using similar degrees of elbow flexion and shoulder and forearm positioning. This test assesses the integrity of the lateral ulnar collateral ligament, and should be performed along with the valgus stress test, to completely evaluate the medial/lateral stability of the ulnohumeral joint.

AQ1

The valgus extension overpressure test has been reported by Andrews et al⁷ to determine whether posterior elbow pain is caused by a posteromedial osteophyte abutting the medial margin of the trochlea and the olecranon fossa. This test is performed by passively extending the elbow while maintaining a valgus stress to it. This test is meant to simulate the stresses imparted to the posterior medial part of the elbow during the acceleration phase of the throwing or serving motion. Reproduction of pain in the posteromedial aspect of the elbow indicates a positive test.

Finally, the moving valgus test described by O'Driscoll et al¹⁰¹ has been recommended to provide a stress to the ulnar collateral ligament and identify ulnar collateral ligament injury. This test is performed with the patient in a seated position with the shoulder abducted 90 degrees in the coronal plane to simulate the throwing motion. The elbow is then flexed to 120 degrees while an external rotation force is maintained by the examiner. This external rotation force creates a valgus load at the elbow. The elbow is then moved from 120 degrees of flexion to 70 degrees of elbow flexion. A positive test involves recreation of medial elbow pain in what has been termed the "shear zone" between 120 and 70 degrees.

This test has resulted in a specificity of 75% and sensitivity of 100% when tested against an arthroscopic evaluation the MUCL. This test can used to determine the integrity of the ulnar collateral ligament in the throwing athlete with medial elbow pain.

The use of provocation tests can be applied when screening the muscle tendon units of the elbow. Provocation tests consist of manual muscle tests to determine pain reproduction. The specific tests, used to screen the elbow joint of a patient with suspected elbow pathology, include wrist and finger flexion and extension as well as forearm pronation and supination.³³ These tests can be used to provoke the muscle tendon unit at the lateral or medial epicondyle. Testing of the elbow at or near full extension can often recreate localized lateral or medial elbow pain with resistive muscle testing (provocation testing) may indicate concomitant tendon injury at the elbow and directs the clinician to perform a more complete elbow examination.

Rehabilitation Techniques for Specific Injuries

Overuse injuries constitute the majority of elbow injuries sustained by the athletic elbow patient, with one of the most common being humeral epicondylitis.^{37,98} Repetitive overuse is one of the primary etiologic factors evident in the history of most patients with elbow dys-function. Epidemiologic research on adult tennis players reports incidences of humeral epicondylitis ranging from 35% to 50%.^{20,55,71,78,109} The incidence reported in elite junior players is significantly less (11% to 12%).¹⁴³

Pathomechanics

AQ2

Etiology of Humeral Epicondylitis

Reported in the literature as early as 1873 by Runge,¹¹⁷ humeral epicondylitis or "tennis elbow," as it is more popularly known, has been studied extensively by many authors. Cyriax, in 1936, listed 26 causes of tennis elbow,²⁵ while an extensive study of this overuse disorder by Goldie, in 1964, reported hypervascularization of the extensor aponeurosis and an increased quantity of free nerve endings in the subtendinous space.⁴⁸ More recently, Leadbetter⁸⁴ described humeral epicondylitis as a degenerative condition consisting of a time-dependent process that includes vascular, chemical, and cellular events that lead to a failure of the cell-matrix healing response in human tendon. This description of tendon injury differs from earlier theories where an inflammatory response was considered as a primary factor; hence Leadbetter⁸⁴ and Nirschl⁹⁶ used the term "tendonosis" as opposed to the original term of "tendonitis."

Nirschl^{95,96} has defined humeral epicondylitis as an extraarticular tendinous injury characterized by excessive vascular granulation and an impaired healing response in the tendon, which he has termed "angiofibroblastic hyperplasia." In the most recent and thorough histopathologic analysis, Nirschl et al⁷⁹ studied specimens of injured tendon obtained from areas of chronic overuse and reported that these specimens did not contain large numbers of lymphocytes, macrophages, and neutrophils. Instead, tendonosis appears to be a degenerative process characterized by large populations of fibroblasts, disorganized collagen, and vascular hyperplasia.⁷⁹ It is not clear why tendonosis is painful, given the lack of inflammatory cells, and it is also unknown why the collagen does not mature or heal typically.

Structures Involved in Humeral Epicondylitis

Nirschl⁹⁶ described the primary structure involved in lateral humeral epicondylitis as the tendon of the extensor carpi radialis brevis. Approximately one-third of cases involve the tendon of the extensor digitorum communis.⁷⁹ Additionally, the extensor carpi radialis longus and extensor carpi ulnaris can be involved as well. The primary site of medial humeral epicondylitis is the flexor carpi radialis, followed by the pronator teres, and flexor carpi ulnaris tendons.^{95,96}

Recent research describes in detail the anatomy of the lateral epicondylar region.^{18,51} The specific location of the extensor carpi radialis brevis tendon lies inferior to the tendinous origin of the extensor carpi radialis longus, which can be palpated along the anterior surface of the supracondylar ridge just proximal or cephalad to the extensor carpi radialis brevis tendon on the lateral epicondyle.¹⁸ Greenbaum et al⁵¹ describe the pyramidal slope or shape of the lateral epicondyle and explain how both the extensor carpi radialis brevis and the extensor communis originate from the entire anterior surface of the lateral epicondyle. These specific relationships are important for the clinician to bear in mind when palpating for the region of maximal tenderness during the clinical examination process. Although detailed recent reports are not present in the literature regarding the medial epicondyle, careful palpation can be used to discriminate between the muscle tendon junctions of the pronator teres and flexor carpi radialis. Additionally, palpation of the MUCL, which originates from nearly the entire inferior surface of the medial epicondyle and inserts into the anterior medial aspect of the coronoid process of the ulna, should be performed. Understanding the involved structures, as well as a detailed knowledge of the exact locations where these structures can be palpated, can assist the clinician in better localizing the painful tendon or tendons involved.

Dijs et al³⁰ studied 70 patients with lateral epicondylitis. They reported the area of maximal involvement in these cases: the extensor carpi radialis longus in only 1% and the extensor carpi radialis brevis in 90%. The body of the extensor carpi radialis tendon was implicated in 1% of cases, and 8% were at the muscle tendon junction over the most proximal part of the muscle of the extensor carpi radialis brevis.

Epidemiology of Humeral Epicondylitis

Nirschl^{95,96} reports that the incidence of lateral humeral epicondylitis is far greater than that of medial epicondylitis in recreational tennis players and in the leading arm of golfers (left arm in a right-handed golfer). Medial humeral epicondylitis is far more common in elite tennis players and throwing athletes, as a result of the powerful loading of the flexor and pronator muscle tendon units during the valgus extension overload inherent in the acceleration phase of those overhead movement patterns. Additionally, the trailing arm of the golfer (right arm in a right-handed golfer) is more likely to have medial symptoms than lateral.

Rehabilitation Progression: Humeral Epicondylitis

Following the detailed examination, a detailed rehabilitation program can commence. Three main stages of rehabilitation can conceptually be applied for the patient: protected function, total-arm strength, and the return to activity phase. Each is discussed in greater detail in this section of the chapter with specific highlights on the therapeutic exercises utilized during each stage of the rehabilitation process.

Protected Function Phase

During this first phase in the rehabilitation process, care is taken to protect the injured muscle tendon unit from stress, but not function. Nirschl^{95,96} cautions against the use of an immobilizer or sling because of further atrophy of the musculature and negative effects on the upper-extremity kinetic chain. Protection of the patient from offending activities is

recommended, with cessation of throwing and serving suggested for medial-based humeral symptoms. Allowing the patient to bat or hit 200 backhands allows for continued activity while minimizing stress to the injured area. Very often however, sport activity must cease entirely to allow the muscle tendon unit time to heal and to most importantly allow formal rehabilitation to progress. Continued work or sport performance can severely slow the progression of resistive exercise and other long-term treatments in physical therapy.

Use of modalities may be helpful during this time period; however, agreement on a clearly superior modality or sequence of modalities has not been substantiated in the literature.^{18,82} A metaanalysis of 185 studies on treatment of humeral epicondylitis showed glaring deficits in the scientific quality of the investigations, with no significantly superior treatment approach identified. Although many modalities or sequences of modalities have anecdotally produced superior results, there is a great need for prospective, randomized, controlled clinical trials in order to identify optimal methods for intervention. Modalities such as ultrasound,^{13,98} electrical stimulation and ice, cortisone injection,^{71,98} nonsteroidal antiinflammatory drugs,¹¹⁵ acupuncture,¹⁹ transverse friction massage,⁶¹ and dimethyl sulfoxide application¹⁰⁶ have all been reported to provide varying levels of relief in the literature. Boyer and Hastings,¹⁸ in a comprehensive review of the treatment of humeral epicondylitis, reported no significant difference with the use of low-energy laser, acupuncture, extracorporeal shockwave therapy, or steroid injection.

The use of cortisone injection has been widely reported in the literature during the pain reduction phase of treatment of this often-recalcitrant condition. Dijs et al³⁰ compared the effects of traditional physical therapy and cortisone injection in 70 patients diagnosed with humeral epicondylitis. In their research, 91% of patients who received the cortisone injection received initial relief, as compared with 47% who reported relief from undergoing physical therapy. After only 3 months the recurrence rate (of primary symptoms) in their subjects, however, was 51% in the cortisone injection group, and only 5% in the physical therapy group. Similar findings were reported in a study by Verhaar et al¹³⁵ comparing physical therapy, consisting of Mills manipulation and cross-friction massage, with corticosteroid injection in a prospective, randomized, controlled clinical trial in 106 patients with humeral epicondylitis. At 6 weeks, 22 of 53 subjects reported complete relief from the cortisone injection, whereas only 3 subjects had complete relief from this type of physical therapy treatment. At 1 year, there were no differences between treatment groups regarding the course of treatment. These results show the short-term benefit from the corticosteroid injection, as well as the ineffectiveness of physical therapy using manipulation and cross-friction massage.

Several recent studies deserve further discussion as they also can be used to direct clinicians in the development of appropriate interventions. Nirschl et al⁹⁷ studied the effects of iontophoresis with dexamethasone in 199 patients with humeral epicondylitis. Results showed that 52% of the subjects in the treatment group reported overall improvement on the investigators' improvement index, with only 33% of the placebo group reporting improvement 2 days after the series of treatments with iontophoresis. One month following the treatment, there was no statistical difference in the overall improvement in the patients in the treatment group versus the control group. One additional finding from this study that has clinical relevance was the presence of greater pain relief in the group that underwent 6 treatments in a 10-day period, as opposed to subjects in the treatment group who underwent treatment over a longer period of time. Although this study does support the use of iontophoresis with dexamethasone, it does not report substantial benefits during follow-up.

Haake et al⁵⁴ studied the effects of extracorporeal shock wave therapy in 272 patients with humeral epicondylitis in a multicenter prospective randomized control study. They reported that extracorporeal shock wave therapy was ineffective in the treatment of humeral epicondylitis. Similarly, Basford et al¹⁰ used low-intensity Nd:YAG laser irradiation at 7 points along the forearm 3 times a week for 4 weeks and reported it to be ineffective in the treatment of lateral humeral epicondylitis.

Based on this review of the literature, it appears that no standardized modality or modality sequence has been identified that is clearly statistically more effective than any other at the present time. Clinical reviews by Nirschl^{95,96} and Ellenbecker and Mattalino³⁷ advocate the use of multiple modalities, such as electrical stimulation and ultrasound, as well as

iontophoresis with dexamethasone, in order to assist in pain reduction and encourage local increases in blood flow. The copious use of ice or cryotherapy following increases in daily activity is also recommended. The use of therapeutic modalities with cortisone injection, if needed, can only be seen as one part of the treatment sequence, with increasing evidence being generated favoring progressive resistive exercise.

Exercise is one of the most powerful modalities used in rehabilitative medicine. Research shows increases in local blood flow following isometric contractions at levels as submaximal as 5% to 50% of maximum voluntary contraction both during the contraction and for periods of up to 1 minute postcontraction.65 Two studies showed superior results in the treatment of humeral epicondylitis using progressive resistive exercise as compared with ultrasound.⁴⁶ In a study by Svernl and Adolffson,¹²⁷ 38 patients with lateral humeral epicondylitis were randomly assigned to a contract relax stretching or eccentric exercise treatment group. Result of this study showed a 71% report of full recovery in the eccentric exercise group, as compared to the group that performed contract-relax stretching, which only found 39% of the subjects rating themselves as fully recovered. These studies support the heavy reliance on the successful application of progressive resistive exercise, with an eccentric component, in the treatment of humeral epicondylitis.

Total-Arm Strength Rehabilitation

Early application of resistive exercise for the treatment of humeral epicondylitis focuses on the important principle that states that "proximal stability is needed to promote distal mobility."126 The initial application of resistive exercise actually consists of specific exercises to strengthen the upper-extremity proximal force couples.⁶² The rotator cuff (deltoid and rotator cuff musculature) and lower trapezius force couples are targeted to enhance proximal stabilization using a low-resistance, high-repetition exercise format (ie, 3 sets of 15, <60 repetition maximum loading). Specific exercises such as side-lying external rotation, prone horizontal abduction, and prone extension, both with externally rotated humeral positions and prone external rotation, all have been shown to elicit high levels of posterior rotator cuff activation during electromyogram research (Figure 21-5).9,15,130 Additionally, exercises such as the serratus press (Figure 21-6) and manual scapular protraction and retraction resistance (Figure 21-7) can be safely applied without stress to the distal aspect of the upper extremity during this important phase of rehabilitation. The use of cuff weights allows some of the rotator cuff and scapular exercises to be







Figure 21-6 Serratus press exercise used to recruit and strengthen the serratus anterior

performed with the weight attached proximal to the elbow, to further minimize overload to the elbow and forearm during the earliest phases of rehabilitation if needed for some patients.

The initial application of exercise to the distal aspect of the extremity follows a pattern that stresses the injured muscle-tendon unit last. For example, the initial distal exercise sequence for the patient with lateral humeral epicondylitis would include wrist flexion and forearm pronation, which provides most of the tensile stress to the medially inserting tendons which are not directly involved in lateral humeral epicondylitis (Figure 21-8). Gradual addition of wrist extension and forearm supination, as well as radial and ulnar deviation exercises are added as signs and symptoms allow. Additional progression is based on the elbow position utilized during distal exercises. Initially, most patients tolerate the exercises in a more pain-free fashion with the elbow placed in slight flexion, with a progression to more extended and functional elbow

positions, as signs and symptoms allow. These exercises are performed with light weights, often as little as 1 lb or 1 kg, as well as tan or yellow Thera-Band, emphasizing both the concentric and eccentric portions of the exercise movement. According to the research by Svernl and Adolffson,¹²⁷ the eccentric portion of the exercise may actually have a greater benefit than the concentric portion; however, more research is needed before a greater and clearer understanding of the role isolated eccentric exercise plays in the rehabilitation of degenerative tendon conditions is achieved. Multiple sets of 15 to 20 repetitions are recommended to promote muscular endurance. Several studies show superior results in the treatment of humeral epicondylitis using progressive resistive exercise. ^{24,82,107,127,132}



Figure 21-7 Manual scapular retraction exercise

Once the patient can tolerate the most basic series of distal exercises (wrist flexion/ extension, forearm pronation/supination, and wrist radial/ulnar deviation), exercises are progressed to include activities that involve simultaneous contraction of the wrist and forearm musculature with elbow flexion/ extension ROM. These include exercises such as exercise ball dribbling (Figure 21-9), the Body Blade (Hymanson, TX), the B.O.I.N.G. arm exerciser device (OPTP, Minneapolis, MN) (Figures 21-10 and 21-11), Thera-Band (Hygenic Corp, Akron, OH), resistance bar external oscillations (Figure 21-12) (which combine wrist and forearm stabilization with posterior rotator cuff and scapular exercise), and seated rowing (Figure 21-13). Additionally, the use of closed-kinetic-chain exercise for the upper extremity is added to promote cocontraction and mimic functional positions with joint approximation (Figures 21-14 to 21-16).35

AQ3



Figure 21-8

Distal upper extremity isotonic exercise patterns, including wrist flexion and extension, radial and ulnar deviation, and forearm pronation and supination.

Svernl & Adolffson¹²⁷ followed 38 patients with lateral humeral epicondylitis who were randomly assigned to a contract-relax stretching or eccentric exercise treatment group. Results of their study showed that 71% of the eccentric exercise group reported full recovery, as compared to 39% of the subjects who performed contract-relax stretching and rated themselves as fully recovered. Croisior et al²⁴ compared the effectiveness of a passive standardized treatment in patients diagnosed with chronic humeral epicondylitis (nonexercise control) to a program that included eccentric isokinetic exercise. After training the

15



Figure 21-9

Ball dribbling using an exercise ball to promote rapid contraction of the musculature in an endurance-oriented fashion. patients in the eccentric exercise group had a significant reduction in pain intensity, an absence of bilateral strength deficit in the wrist extensors and forearm supinators, improved tendon imaging and improved disability status with rating scales.

Tyler et al¹³² used an elastic based flexible bar (Thera-Band Flexbar, Hygenic Corp, Akron, OH) to provide an eccentric based overload to the wrist and forearm musculature in addition to a traditional rehabilitation program. Results of their research, performed initially on patients with lateral humeral epicondylitis using a twisting type exercise to eccentrically load the extensor musculature in an elbow-extended position, showed superior results to traditional rehabilitation exercises alone.¹³² The reader is referred to the Tyler et al article for the specific exercise sequence used for both medial and lateral humeral epicondylitis. Using the Flexbar to preload the wrist and finger musculature is performed followed by a slow eccentric contraction of the wrist and finger musculature during this exercise sequence. Multiple sets of 15 repetitions are recommended by the researchers,¹³² with slight levels of discomfort (Visual Analog Scale [VAS]



Figure 21-10Oscillatory exercise using theAQ4boing device



Figure 21-11 Oscillatory exercise using the Body Blade device

Rehabilitation Progression: Humeral Epicondylitis



Figure 21-12 Oscillatory exercise using the Thera-Band flex bar

Oscillations can be performed in a sagittal and frontal plane direction to target specific muscle group activation.



Figure 21-13 Seated rowing exercise used for proximal stabilization and total-arm strength



Figure 21-14 Quadruped rhythmic stabilization exercise

17

18



Figure 21-15 Closed-chain upper-extremity exercise using the BOSU platform



Figure 21-16 Pointer closed-chain upper extremity exercise using the Body Blade to promote instability in the open-chain limb and a medicine ball under the closed-chain limb

levels 3 to 4) during the exercise being allowed, which is similar to other types of eccentric training programs.⁸² The addition of this exercise, coupled with eccentric wrist flexion exercises with elastic tubing or bands for multiple sets, is used to provide a controlled overload to the wrist, forearm, and finger musculature in this stage of the rehabilitation program. These site-specific exercises are integrated with total extremity focus as described above, including the scapular stabilizers and rotator cuff, to complete the comprehensive rehabilitation program.

Most recently, Peterson et al¹⁰⁷ studied a group of 81 patients with a 3-month history (mean duration: 107 weeks) of chronic lateral elbow pain. Patients were randomly allocated to an exercise group or a control group for a 3-month period of either concentric and eccentric exercise (exercise group) or a "wait-and-see" control group. Exercises consisted of controlled wrist flexion and extension starting with a 1 kg (women) or 2 kg (men) water container that was increased by one-tenth (1 dL of water) into the container with subjects performing 45 repetitions (3 sets of 15 repetitions). After 3 months of training, subjects in the exercise group had a greater relief of pain with a maximal muscle test provocation and elongation provocation test. Specifically, 72% of the subjects in the exercise group had a 30% diminution in pain during the maximal voluntary muscle provocation test as compared with 44% in the control group. This study demonstrates the continued support of an exercise-based approach to elbow tendon pathology.

In addition to the resistive exercise, the use of gentle passive stretching to optimize the muscle tendon unit length is indicated. Combined stretches with the patient in the supine position are indicated to elongate the biarticular muscle tendon units of the elbow, forearm and wrist using a combination of elbow, and wrist and forearm positions (Figure 21-17). Additionally, stretching the distal aspect of the extremity in varying positions of glenohumeral joint elevation is also indicated.³⁷ Mobilization of the ulnohumeral joint can also be effective in cases where significant flexion contractures exist. Use of ulnohumeral distraction with the elbow near full extension will selectively tension the anterior joint capsule (Figure 21-18).¹⁷



Figure 21-17 Passive stretching of the wrist and forearm musculature

A. Wrist flexion and pronation to stretch the wrist extensors, and (B) wrist extension and supination to stretch the flexors and pronators of the distal upper extremity.



Figure 21-18 Ulnohumeral joint distraction mobilization

Altering the position of elbow flexion and extension selectively stresses portions of the anterior and posterior capsule.



Figure 21-19 Isokinetic wrist flexion/ extension exercise on the Cybex 6000 isokinetic dynamometer

As the patients tolerate the distal isotonic exercise progression pain-free at a level of 3 to 5 pounds or medium-level elastic tubing or bands, as well as demonstrate a tolerance to the oscillatory type exercises in this phase of rehabilitation, they are progressed to the isokinetic form of exercise. Advantages of isokinetic exercise are the inherent accommodative resistance and utilization of faster, more functional contractile velocities, in addition to providing isolated patterns to elicit high levels of muscular activation. The initial pattern of exercise used anecdotally has been wrist flexion/extension



Figure 21-20 Isokinetic forearm pronation/ supination exercise on the Cybex 6000 isokinetic dynamometer

(Figure 21-19), with forearm pronation/supination (Figure 21-20) added after successful tolerance of a trial treatment of wrist flexion/extension. Contractile velocities ranging between 180 and 300 degrees per second, with 6 to 8 sets of 15 to 20 repetitions, are used to foster local muscular endurance.⁴⁵ In addition to isokinetic exercise, plyometric wrist snaps (Figure 21-21) and wrist flips (Figure 21-22), as well as upper-extremity patterns, are utilized to begin to train the elbow for functional and sport specific demands.

Return to Activity Phase

Of the 3 phases in the rehabilitation process for humeral epicondylitis, return to activity is the one that is most frequently ignored or cut short, resulting in serious potential for reinjury and the development of a "chronic" status of this injury. Objective criterion for entry into this stage are tolerance of the previously stated resistive

Rehabilitation Progression: Humeral Epicondylitis



Figure 21-21 Plyometric wrist snap used for explosive training of the wrist and finger flexor muscle groups



Figure 21-22 Plyometric wrist flip used for explosive training of the wrist and finger flexor muscle groups

exercise series, objectively documented strength equal to the contralateral extremity with either manual muscle testing or, preferably, isokinetic testing distal grip strength measured with a dynamometer, and functional ROM. It is important to note that often in the elite athlete, chronic musculoskeletal adaptations exist that prevent attainment of full elbow ROM. Recall that this is often secondary to the osseous and capsular adaptations discussed earlier in this chapter.

Characteristics of interval sport return programs include alternate day performance, as well as gradual progressions of intensity and repetitions of sport activities. For example, utilizing low-compression tennis balls such as the Pro-Penn Star Ball (Penn Racquet Sports, Phoenix, AZ) or Wilson Gator Ball (Wilson Sporting Goods, Chicago, IL) during the initial contact phase of the return to tennis decreases impact stress and increases tolerance to the activity. Performing the interval program under supervision, either during therapy or with a knowledgeable teaching professional or coach, allows for the biomechanical evaluation of technique and guards against overzealous intensity levels, which can be a common mistake in well-intentioned, motivated patients. Using the return program on alternate days, with rest between sessions, allows for recovery and decreases the potential for reinjury.

Two other important aspects of the return to sport activity are the continued application of resistive exercise and the modification or evaluation of the patient's equipment. 21



Figure 21-23 Counterforce brace applied the elbow for a patient with lateral humeral epicondylitis

Continuation of the total-arm strength rehabilitation exercises using elastic resistance, medicine balls, and isotonic or isokinetic resistance is important to continue to enhance not only strength but also muscular endurance. Inspection and modification of the patient's tennis racquet or golf clubs is also important. For example, lowering the string tension several pounds and ensuring that the player uses a more resilient or softer string, such as a coreless multifilament synthetic string or gut, is widely recommended for tennis players with upperextremity injury histories.95,96,98 Grip size is also very important with research showing changes in muscular activity with alteration of handle or grip size.¹ Measurement of proper grip size has been described by Nirschl as corresponding to the distance between the distal tip of the ring finger along the radial border of the finger to the proximal palmar crease.95 Nirschl has also recommended the use of a counterforce brace (Figure 21-23) in order to decrease stress on the insertion of the flexor and extensor tendons during work or sport activity.52

Additional Treatments Presently Used for Tendon Injury

Platelet-Rich Plasma

Platelet-rich plasma (PRP) is a treatment modality that can be utilized in many orthopedic injuries involving tendon and ligament. Such treatment involves localized injections of PRP at various concentrations into the injured tissues, which has been theorized to improve healing by delivering a high concentration of platelets to the injured region.⁸ Research demonstrates that platelets are involved in healing through clot formation and the release of growth factors and cytokines, although which specific factors and how they are regulated is still not completely understood. Growth factors in the PRP concentrate include, but are not limited to, transforming growth factor β_1 , platelet-derived growth factor, vascular endothelial growth factor, epithelial growth factor, hepatocyte growth factor, and insulin-like growth factor 1.⁴⁴ No classification system currently exists to regulate PRP preparation, including regulation of methods of platelet concentration, activation, and the presence of white blood cell concentration. As a result, much of the literature that relates to the use of PRP is difficult to cross-reference and compare despite, recent attempts to unify a system.²⁹

The literature supporting the use of PRP treatment for tendon injuries demonstrates mixed results with variable success related to the location of the injured tendons and ligaments. Various cell culture and animal studies demonstrate the efficacy of PRP. In one animal study, PRP used in posttendon repair not only increased healing strength and load-to-failure, it did so without increasing adhesion formation or inflammation 2 weeks following surgery. Although many of the animal studies are encouraging, the results in human studies have been limited.^{120,129} During 1 large, stratified, block-randomized, double-blind, placebo-controlled trial by deVos, it was concluded that PRP injection therapy did not improve pain and activity when compared to saline injections used with controls. Although this study was performed on patients with chronic Achilles tendinopathy, it illustrates the equivocal nature of PRP treatment.²⁸

Since the deVos study was released in 2006 there have been numerous other PRP studies exhibiting variable success which is often dependent upon the anatomical area of administration. One such area in which treatment with PRP has been encouraging and has almost become an established treatment based on level I data is lateral and medial epicondylar tendinopathies. A 2006 level II cohort study comparing PRP and bupivacaine injection for elbow epicondylitis resulted in statistically significant improvement in patients' VAS for pain score and Mayo elbow score. Of note, the study excluded patients taking nonsteroidal antiinflammatory drugs, a common treatment currently utilized for such diagnoses.⁹¹ Further evidence supporting PRP has emerged in a level 1 double-blinded randomized control trial of patients with lateral epicondylitis. This study included patients that had failed nonsteroidal antiinflammatory drug therapy, physical therapy, bracing, and other conservative therapies commonly used. Patients were randomized and received either a PRP injection or corticosteroid injection and were then followed for 1 and eventually 2 years. The PRP group had better improvement with fewer interventions and operations, with concurrent reductions in the disabilities of the arm, shoulder, and hand and VAS scores even after 2 years. Furthermore, there were no reported complications with the PRP treatment.^{49,105} In a similar randomized control study that included lateral epicondylitis and plantar fasciitis, PRP outperformed corticosteroid injections with significant improvement in function and pain.¹⁰⁴

More recent studies have compared PRP with autologous whole blood in the treatment of lateral epicondylitis. While the patients receiving PRP consistently performed better in a level 1 randomized, controlled study, only one time point at 6 weeks showed any statistically significant difference.¹²⁸ A second study utilizing a similar model demonstrated no difference between the 2 groups at 6 months.²³ These results, however, are not straightforward because of confounding factors of red blood cells and white blood cells possibly playing a role in the healing process. More research is needed to decipher the appropriate concentrations of PRP and whether other blood components should be included in order to positively impact healing.

Postoperative Rehabilitation Progression

In a study of more than 3000 cases of humeral epicondylitis, Nirschl⁹⁶ has reported that 92% respond to nonoperative treatment. Characteristics of patients who often require surgical correction for this condition are failure of nonoperative rehabilitation programs, minimal relief with corticosteroid injection, and intense pain in the injured elbow even at rest. Surgical treatment for lateral humeral epicondylitis, as reported by Nirschl,⁹⁶ involves a small incision from the radial head to 1 inch proximal to the lateral epicondyle. Through this incision, Nirschl removes the pathologic tissue he termed *angiofibroblastic hyperplasia*, without disturbing the attachment of the extensor aponeurosis, in order to preserve stability of the elbow.⁹⁶ Vascular enhancement is afforded by drilling holes into the cortical bone in the anterior lateral epicondyle to cancellous bone level. Postoperative immobilization is brief (48 hours), with early motion of the wrist and fingers on postoperative day 1, progressing to elbow active assistive ROM during the first 2 to 3 weeks. Resistive exercise is gradually applied after the third postoperative week, with a return to normal daily activities expected at 8 weeks postoperatively and a return to sport activity several months thereafter.^{95,96}

Rehabilitation Following Elbow Arthroscopy

Repetitive stresses to the athletic elbow often result in loose body formation and osteochondral injury, in addition to the more commonly reported tendon injury resulting in humeral epicondylitis. Andrews and Soffer⁴ report that the most common indications for elbow arthroscopy are loose body removal and removal of osteophytes. Posteromedial decompression includes the excision of osteophytes, with or without resection of additional posteromedial bone from the proximal olecranon.³ Early emphasis on regaining full-extension ROM is possible because of the minimally invasive arthroscopic procedure. The senior author's postoperative protocol following arthroscopic procedures of the elbow is presented in Appendix 1. Progressive application of resistive exercise to increase both strength and local muscle endurance forms the bulk of the rehabilitation protocol. Use of early shoulder and scapular stabilization is also recommended in these patients in preparation to the return to overhead activities and aggressive functional activity following discharge.

Outcomes following elbow arthroscopy for posteromedial osteophyte and loose body removal were reported by Oglive-Harris et al,¹⁰² where 21 patients were followed for an average of 35 months postoperatively, rendering good and excellent results in 7 and 14 patients, respectively. O'Driscoll and Morrey¹⁰⁰ reported that arthroscopic removal of loose bodies was of benefit in 75% of all patients; however, when loose bodies were not secondary to some other intraarticular condition, 100% of patients rated the procedure as beneficial. Andrews and Timmerman⁵ reviewed the results of 73 cases of arthroscopic elbow surgery in professional baseball pitchers. Eighty percent of players were able to return to full activity, returning to pitching at their preinjury level for at least 1 season. Further review of these patients found that 25% returned for additional surgery, often requiring stabilization and reconstruction of the ulnar collateral ligament as a result of valgus instability. This important study shows the close association between medial elbow laxity and posterior medial osteochondral injury and highlights the importance of identifying subtle instability in the athletic elbow.

Reddy et al¹¹⁰ retrospectively reviewed a sample of 172 patients who underwent elbow arthroscopy and had a mean follow-up of 42 months. Fifty-six percent of these patients had an excellent result, which allowed them a full return to activity, with 36% having a good result. A 1.6% complication rate was reported, with an overall conclusion that this procedure is both safe and efficacious for the treatment of osteochondral injury of the elbow.

Ellenbecker and Mattalino³⁷ measured muscular strength at a mean of 8 weeks postoperatively in 8 professional baseball pitchers following arthroscopic removal of loose bodies and posteromedial olecranon spur resection. Results showed a complete return of wrist flexion/extension strength and forearm pronation/supination strength at 8 weeks following arthroscopy. This allows for a gradual progression to interval sport return programs between 8 and 12 weeks postoperatively.

Valgus Extension Overload Injuries

Repeated activities, such as overhead throwing, tennis serving, or throwing the javelin, can lead to characteristic patterns of osseous and osteochondral injury in both the older active patient, as well as the adolescent elbow. These injuries are commonly referred to as valgus extension overload injuries.¹⁴²

Pathomechanics

As a result of the valgus stress incurred during throwing or the serving motion, traction placed via the medial aspect of the elbow can create bony spurs or osteophytes at the medial epicondyle or coronoid process of the elbow.^{11,60,123} Additionally, the valgus stress during elbow extension creates impingement, which leads to the development of osteophyte formation at the posterior and posteromedial aspects of the olecranon tip, causing

chondromalacia and loose body formation.¹⁴² The combined motion of valgus pressure with the powerful extension of the elbow leads to posterior osteophyte formation, because of impingement of the posterior medial aspect of the ulna against the trochlea and olecranon fossa. Joyce⁷⁰ has reported the presence of chondromalacia in the medial groove of the trochlea, which often precedes osteophyte formation. Erosion to subchondral bone is often witnessed when olecranon osteophytes are initially developing. Injury to the ulnar collateral ligament and medial muscle-tendon units of the flexor-pronator group can also occur with this type of repetitive loading.^{60,144}

During the valgus stress that occurs to the human elbow during the acceleration phase of both the throwing and serving motions, lateral compressive forces occur in the lateral aspect of the elbow, specifically at the radio-capitellar joint. Of great concern in the immature pediatric throwing athlete is osteochondritis dissecans and Panner disease.^{37,70} Both of these injuries are covered in Chapter 30. In the older adult elbow, the radiocapitellar joint can be the site of joint degeneration and osteochondral injury from the compressive loading.⁶⁰ This lateral compressive loading is increased in the elbow with MUCL laxity or ligament injury.³⁷

Ulnar Collateral Ligament Injury

Pathomechanics and Mechanism of Injury

Attenuation of the ulnar collateral ligament can produce valgus instability of the elbow, which can lead to medial joint pain, ulnar nerve compromise, and lateral radiocapitellar and posterolateral osseous dysfunction, which results in severe dysfunction in the throwing or racquet sport athlete. The repetitive valgus loading that occurs in the elbow during the acceleration phase of the throwing or serving motion can attenuate this structure. Sprains and partial thickness tears of the MUCL can occur and progress to complete tears and avulsions of the ligament from its bony attachments.³¹

Rehabilitation Concerns

Nonoperative rehabilitation of the athlete with an ulnar collateral ligament sprain also involves the primary stages outlined in the rehabilitation of humeral epicondylitis. During the initial stage of rehabilitation, immobilization of the elbow is often a characteristic part of the process to decrease pain and enhance healing. Either an immobilizer or hinged brace is used to limit end ranges of elbow extension and flexion. Modalities are again used to assist in the healing process, as are gentle ROM, submaximal isometrics, and manual resistance of both wrist and forearm midrange movements.

Rehabilitation Progression

Use of a total-arm strength rehabilitation protocol is indicated to facilitate both muscular strength and endurance to the elbow, forearm, and wrist. In addition to previously mentioned exercises, particular attention is given to eccentric muscle work of the wrist flexors and forearm supinators to attempt to dynamically support the attenuated ulnar collateral ligament. Because of the intimate association between the flexor carpi ulnaris and the ulnar collateral ligament, early strengthening in the pattern of wrist flexion and ulnar deviation may provoke symptoms; however, later in rehabilitation, the repeated use of exercises to strengthen the muscles directly overlying the injured ligament to provide dynamic stabilization is highly recommended.²⁶

In addition to distal strengthening, significant emphasis is placed on strengthening of the rotator cuff and scapular stabilizers of the throwing athlete with ulnar collateral ligament injury. In addition to increasing strength and endurance of the scapular stabilizers and rotator cuff musculature, attention is also directed toward the evaluation of shoulder ROM and specifically to the range of rotational ROM. Dines et al³¹ has identified increased glenohumeral internal rotation ROM deficits in throwing athletes with ulnar collateral ligament injury as compared to cohorts of throwing athletes without medial elbow injury. This finding highlights the importance of evaluation and treatment of the entire upper extremity kinetic chain in the throwing athlete with ulnar collateral ligament injury. The application of specific interventions directed to stretch the posterior shoulder ⁶⁴ to improve internal rotation ROM is recommended based on this new finding. Wilk et al¹⁴¹ and Shanley et al¹²¹ both have shown increases in shoulder injury risk with losses of approximately 12 degrees of internal rotation ROM¹⁴¹ in baseball pitchers.

Progression to plyometric exercises, which impart a submaximal, controlled valgus stress to the medial aspect of the elbow such as a 90/90 shoulder and elbow medicine ball toss in later stages of rehabilitation, attempts to simulate loads placed on the medial elbow (Figure 21-24). Use of the isokinetic dynamometer for distal strengthening is also recommended, with additional training focused on the shoulder for internal/external rotation with the arm abducted 90 degrees and elbow flexed 90 degrees (Figure 21-25). Use of this position imparts a controlled valgus stress to the elbow in addition to strengthening the rotator cuff.³⁶



Figure 21-24

Plyometric 90/90 medicine ball toss to simulate loads placed to the medial elbow in the later stages of rehabilitation only to prepare the overhead athlete for a return to throwing.



Figure 21-25 Isokinetic 90/90 internal/ external rotation training position on the Cybex isokinetic dynamometer

A complete return of ROM and isokinetically documented appropriate elbow, forearm, and wrist strength are required before an interval program is initiated. Reoccurrence of pain, feelings of instability, or neural irritation with throwing or functional activity identify the patient as a potential candidate for an ulnar collateral ligament repair or reconstruction. It should be noted that many patients who undergo nonoperative rehabilitation may progress to the need for operative intervention.

Postoperative Rehabilitation Following Ulnar Collateral Ligament Reconstruction

Operative procedures for the athlete with valgus instability of the elbow have focused on direct primary repair of the ligament⁸¹ as well as utilization of an autogenous graft for reconstruction of the medial elbow. Conway et al,²² Jobe et al,⁶⁸ and Regan et al¹¹¹ reported that the palmaris tendon used as the autogenous graft, harvested from the ipsilateral forearm, fails at higher loads (357 N) and is 4 times stronger than the native anterior band of the ulnar collateral ligament, which fails at 260 N.

In a retrospective study by Conway et al²² of 71 throwing athletes who underwent either surgical repair or reconstruction of the ulnar collateral ligament, 87% were found to have a midsubstance tear of the ulnar collateral ligament, 10% had a distal ulnar avulsion, and only 3% avulsed from the medial epicondyle. Thirty-nine percent of these elbows had calcification and scar formation in the ulnar collateral ligament with 16% demonstrating an osteophyte to the posteromedial olecranon most likely from the increased valgus extension overload secondary to ulnar collateral ligament attenuation.

The clinical evaluation of these patients preoperatively resulted in a positive valgus stress test in 8 of the 14 patients who underwent an ulnar collateral ligament repair, and 33 of 56 patients who underwent autogenous reconstruction. Valgus stress radiographs were also used in the preoperative evaluation with greater emphasis placed upon the subjective and clinical evaluation.²² Fifty percent of these athletes demonstrated a flexion contracture that limited full elbow extension.

Surgical Technique for Ulnar Collateral Ligament Reconstruction

The surgical technique used to reconstruct the ulnar collateral ligament is described extensively by Conway et al,²² Jobe et al,⁶⁸ and Jobe and Elattrache.⁶⁶ A 10-cm medial incision over the medial epicondyle is used to provide exposure with careful dissection and protection of the ulnar nerve carried out before the ulnar collateral ligament is addressed. If a primary repair is performed, adequate normal-appearing ligamentous tissue is required to allow for direct repair. If inadequate ligamentous tissue is present, a reconstruction is performed. Additional exposure is required to perform the reconstruction, which is obtained by transection of the flexor/pronator tendinous origin.

This has important ramifications with respect to rehabilitation. The removal of this tendinous origin results in a greater amount of time required for healing, and a longer time period before resistive exercise of the flexor/pronator muscles and forearm supination and wrist extension ROM can be performed.

Calcification within the ligament and surrounding soft tissues is also removed with relocation of the ulnar nerve performed by removing it from the cubital tunnel. The ulnar nerve is mobilized from the level of the arcade of Struthers to the interval between the two heads of the flexor carpi ulnaris. The attachment sites of the anterior band of the ulnar AQ6

collateral ligament are identified and tunnels are drilled in the medial epicondyle and proximal ulna to approximate the anatomical location of the original ligament. The graft taken from the ipsilateral palmaris longus (if available) is then placed in a figure-of-8 fash-ion through the tunnels. The ulnar nerve is carefully transposed so that no impingement or tethering occurs. Reattachment of the flexor pronator origin is then performed. The elbow is immobilized in a position of 90 degrees of flexion, neutral forearm rotation, with the wrist left free to move.

Rehabilitation Concerns

The elbow remains immobilized for the first 10 days postoperatively, with gentle gripping exercises allowed in order to prevent further disuse atrophy. Active and passive ROM of the elbow, wrist, and shoulder are performed at 10 days postoperatively. Close monitoring of the ulnar nerve distribution in the distal upper extremity is recommended because of the transposition of the nerve that frequently accompanies surgical reconstruction of the MUCL. As discussed in the surgical summary previously, care is taken to protect the graft by gradually progressing elbow extension ROM to 30 degrees by week 2 and finally to terminal ranges by 4 to 6 weeks postoperatively. Protection of the graft from large stresses is recommended, even though loss of extension ROM is an undesirable postoperative result. Therefore, progressive increases in elbow extension ROM and the use of gentle joint mobilization and contract-relax stretching techniques are warranted to achieve timely, optimal elbow extension. Because of the reattachment of the flexor-pronator tendinous insertion, limited ROM into wrist extension and forearm supination is performed for the first 6 weeks until healing of the flexor-pronator insertion takes place.

Rehabilitation of the postoperative elbow should also include activities to restore proprioceptive function to the injured joint. Kinesthesia is the perceived sensation of the position and movement of joints and muscles and an important part in the coordination of movement patterns in the peripheral joints. Simple use of exercises such as angular replication and end-range reproduction can be used early in rehabilitation, without visual assistance, to stimulate mechanoreceptors in the postoperative joint. These procedures are utilized early in the rehabilitation process concomitant with ROM and joint mobilization. Loss of kinesthetic awareness in the upper extremity following injury has been objectively identified by Smith and Brunolli.¹²⁴

Rehabilitation Progression

The progression of resistive exercise follows previously discussed exercises, beginning with multiple-angle isometrics at week 2 and submaximal isotonics during the fourth postoperation week. Utilization of the total-arm strength concept is followed, with proximal weight attachment for glenohumeral exercises to prevent stresses placed across the elbow. No glenohumeral joint, internal or external rotation strengthening, is allowed for at least 6 weeks to as many as 16 weeks postoperation, because of the valgus stress placed upon the elbow with this movement pattern. During weeks 8 to 12 following surgery, both concentric and eccentric exercises are performed in the elbow extensors and flexors, as well as a continued total-arm strengthening emphasis, with all distal movement patterns described in nonoperative rehabilitation of humeral epicondylitis being applied. Plyometric exercises, ball dribbling, and closed-chain exercises are also introduced during this time frame.

Isokinetic training is introduced at 4 months postoperation, with isokinetic testing applied to identify areas needing specific emphasis.^{139,140} Progression of isokinetic training patterns by these authors again follows from wrist extension/flexion to forearm pronation/ supination, and, finally, to elbow extension/flexion. The isokinetic dynamometer is also

used at 4 to 6 months postoperatively for shoulder internal/external rotation strengthening with 90 degrees of abduction and 90 degrees of elbow flexion to impart a gentle, controlled valgus stress to the elbow. At 4 months postoperation, throwing athletes begin an interval-throwing program to prepare the elbow for the stresses of functional activity.

The duration of rehabilitation postoperatively is often 6 months to a year. A slow revascularization of the graft through a sheath of granulation tissue that grows from the tissue adjacent to the site of implantation encircles the graft is the rationale provided by Jobe et al⁶⁸ for their time-based rehabilitation program. They are convinced that at least 1 year is required for the tendon graft and its surrounding tissues to develop sufficient strength and endurance to function as a ligament in the medial elbow.

Outcomes Following Ulnar Collateral Ligament Reconstruction

In their series of 56 reconstructed elbows, Conway et al²² reported baseball players return to throwing 15 feet by 4.5 months, with competition at 12.5 months postoperation. The athlete with a repaired ulnar collateral ligament performed throwing activities of 15 feet at 3 months and competed at 9 months. Overall, an excellent result was achieved in 64% of the operative elbows of elite athletes. An excellent result was defined as achieving a level of activity equal to or greater than preinjury level. Bennett et al¹² reported improved stability in 13 of 14 cases of ulnar collateral ligament reconstruction in an active adult and working population, with improved stability reported in all cases of direct repair by Kuroda and Sakamaki.⁸¹ A flexion contracture was reported in as many as 50% of the athletes at a mean of six years following an autogenous ulnar collateral ligament reconstruction.²² Conway et al²² did not feel that this finding limits performance, since elbow ROM during throwing ranges from 120 degrees to 20 degrees, although conscious effort during rehabilitation is given to regain as much extension as possible during the time-based rehabilitation program.

Elbow Dislocations

Failure of the normally stable osseous, ligamentous, capsular, and muscular constraints at the elbow ultimately can lead to dislocation in response to a macrotrauma.

Pathomechanics

The elbow is the second most commonly dislocated large joint behind the shoulder in the adult population and the most commonly dislocated joint in children younger than the age of 10 years.⁸⁶ It is reported that 7 of every 100,000 people suffer an elbow dislocation.⁶⁹ Inherent in any elbow dislocation is a degree of instability present at the joint. Rehabilitation and treatment are predicated upon regaining full functional mobility while maintaining elbow joint stability.

Mechanism of Injury

Elbow dislocations are typically the result of trauma as the person falls onto an outstretched arm. Two specific mechanisms of injury have been reported. Hyperextension along with an axially directed force causes the olecranon to act as a fulcrum, levering the trochlea over the coronoid process.⁸⁶ A posterolateral rotary-directed force can produce a rotational displacement of the ulna on the humerus leading to dislocation.⁹⁹ A combination of axial

compression, elbow flexion, valgus stress, and forearm supination produces this type of displacement. Concomitant injuries associated with elbow dislocations include fractures, soft tissue tear or rupture of ligaments, muscles, and joint capsule, vascular and neural compromise, as well as articular cartilage defects. Following the dislocation event, the elbow typically presents with significant swelling, severe pain, and structural deformity with the forearm appearing shortened upon observation.

Classification

Traditionally, elbow dislocations are classified according to the direction of ulnar displacement relative to the humerus. The overwhelming majority of cases involve a posterior dislocation versus the rare incidence of both anterior and lateral dislocation. Posterior dislocations are further subdivided into posterior, posteromedial, and posterolateral groups. Approximately 90% of all elbow dislocations are posterior and posterolateral.⁶ Other classifications include simple versus complete dislocations. Simple dislocations involve minimal disruption of the congruity of bony and soft-tissue restraints, which usually allow for early initiated motion and rehabilitation. Complete dislocations involve the destruction of the bony restraints and soft tissue, particularly the ulnar collateral ligament. The ulnar collateral ligament and bony articulation provide the majority of stability at the elbow absorbing 54% and 33% of the valgus forces at 90 degrees of elbow flexion and 31% each at 0 degrees of elbow flexion.⁹³ Complete dislocations generally require a longer immobilization and recovery period to allow for healing of the primary restraints. Further classification is used to describe posterolateral instability as it progresses to dislocation. This classification is divided into 3 stages and based upon a circular disruption of bone and soft tissue that starts laterally and progresses toward the medial side of the elbow.⁹⁹ Stage 1 involves a partial or complete rupture of the lateral collateral ligament resulting in subluxation. In stage 2, the entire lateral collateral ligament is ruptured along with part of the anterior and posterior capsule leading to a *perched* dislocation. Perched refers to the position of the coronoid process as it sits "perched" on the posterior aspect of the trochlea. Stage 3 posterolateral dislocations are considered complete dislocations. Stage 3A involves all soft tissues around the elbow including the posterior band of the ulnar collateral ligament with the exception of the anterior band. In stage 3B, complete disruption of both lateral and ulnar collateral ligament complexes results in gross multidirectional instability.

Rehabilitation Concerns

Immediate care of elbow dislocations initially involves reduction, evaluation of the neurovascular triad for compromise, and further assessment of ligamentous stability. Radiographs and MRI are obtained to determine the extent of bony and soft-tissue damage. The elbow is typically placed in a posterior splint at 90 degrees flexion and immobilized until cleared to begin ROM activities. Severe damage to bony and soft-tissue restraints may require surgical intervention.

Rehabilitation Progression

Elbow rehabilitation guidelines following dislocation comprise 3 distinct phases, as proposed by Harrelson and Leaver-Dunn.⁵⁶ Phase 1 is the immediate motion phase and generally starts anywhere from 1 to 10 days postinjury. Early active ROM (all planes) within a protected and pain-free range is initiated to prevent adhesion formation and flexion contracture, which causes subsequent loss of motion and pain. For simple dislocations, immediate motion protocols have been shown to produce favorable results including return of full motion, early return to athletic and competitive activities, and low incidence

of recurrent instability.^{116,133,134} Passive ROM is not indicated early because of the possibility of heterotopic ossification. Management of pain and inflammation is conducted with ice, compression, and use of modalities. Strengthening activities can include gripping, shoulder and wrist isotonics, and gentle multiangle submax-to-max isometrics for both elbow flexion and extension. All exercises should be completed in a pain-free ROM. Care should be taken to avoid valgus stresses at the elbow. The posterior splint is usually discharged; however, a hinged elbow brace may be utilized to protect ROM within the limits of stability.

Phase 2 consists of the intermediate phase from days 10 to 14. During this period chief concern is achieving full elbow ROM particularly extension. Strength, endurance, and power exercise are progressed to include elbow isotonics in all planes. Progressive resistive exercises are to be incorporated for the shoulder, wrist, and elbow. Inclusion of proprioceptive activities, rhythmic stabilization, plyometrics, and eccentric isotonics during the latter parts of this phase helps retrain the dynamic elbow stabilizers. Phase 3 is the advanced strengthening phase beginning from week 2 to 6. During this phase preparation is made for a gradual return to sport or activity. Exercise progression is to include sport specific activities and drills along with continued progressive resistive exercise. At this time, an interval-throwing program may be initiated for those returning to overhand throwing activities. Wilk and Arrigo¹³⁸ also include a return to activity phase as part of a general rehabilitation protocol. Sport-specific exercise and tests are conducted to determine appropriate stability requirements on the elbow. Upon clinical examination by the physician, ROM should be full and no pain present. Medical doctor clearance is ultimately required for return to activity. Bracing or taping may continue to be used to ensure stability and joint protection.

Elbow Fractures

Pathomechanics and Mechanism of Injury

Fractures that affect function at the elbow joint may occur at the distal humerus, capitellum, coronoid, olecranon, radial head and neck, supracondylar region, lateral condyle, and medial epicondyle. These fractures occur in both children and adults as the result of an acute traumatic injury, such as a direct collision or a fall on an outstretched hand. A thorough clinical examination and radiographs are important for obtaining a correct diagnosis so that appropriate treatment can be given. Clinical signs and symptoms of a fracture include history of traumatic onset, pain, swelling, tenderness, and ecchymosis. Elbow stability and neurovascular status should also be assessed immediately following injury. The presence of the posterior fat pad sign on radiographs has been suggested as a sign of an intracapsular elbow fracture in pediatric patients even if no fracture is seen on the radiograph. Effusion within the elbow joint elevates the posterior fat pad, making it visible on radiographs. In a prospective study, the presence of a posterior fat pad on radiographs was indicative of a fracture in 76% of the children evaluated. These results suggest that the children with an elevated posterior fat pad sign should be treated as though a nondisplaced elbow fracture is present, even if the fracture is not evident on radiographs.¹²²

Types of Elbow Fractures

Supracondylar Fractures

Supracondylar fractures are the most common elbow fractures that occur in children and account for 60% of all elbow fractures.^{32,89} They often occur in children who are around 7 years old.²⁷ The mechanism of injury is a fall on a hyperextended arm with pronation.^{27,32} Because the supracondylar ridge is only 2 to 3 mm thick in children,³² it has a high risk

for injury with a hyperextension mechanism. The Gartland classification system is used to divide supracondylar fractures into 3 types.^{32,89} Type I fractures are nondisplaced and usually treated with 3 weeks of immobilization. Type II fractures are moderately displaced, but there is contact between the fragments as the posterior periosteal hinge is intact. A complete displacement is classified as type III. Posteromedial displacement is associated with radial nerve injuries, and posterolateral displacement is associated with brachial artery or median nerve injury. Reduction and surgical stabilization is required for type III, and possibly for type II fractures.^{32,89} Three to 4 weeks of immobilization is recommended following surgery.²⁷ Complications following supracondylar injury may include cubitus varus, transient nerve injury, and compartment syndrome.³²

Full elbow ROM can be difficult to regain after supracondylar fractures and rehabilitation may last several months.²⁷ Loss of ROM will vary based on patient age, injury severity, and concomitant injuries. Keppler et al⁷² investigated the effectiveness of physiotherapy in regaining elbow ROM after uncomplicated, operative treatment supracondylar humeral fractures without neurovascular injury in children between the ages of 5 and 12 years. At 12 and 18 weeks following surgery, results showed a significant improvement in elbow ROM in those children receiving physiotherapy compared to those not receiving treatment. However, at a 1-year follow-up, there was no significant difference between the children who had received physical therapy and those who did not.

Lateral Condyle Fractures

Lateral condyle fractures account for 12% to 20% of elbow fractures in children,^{14,32,83,89} and are the second most common elbow fracture.⁸³ These fractures result from a fall on an outstretched hand with forearm supination.^{89,90} A varus force may cause the extensor muscles and collateral ligament to avulse the lateral condyle.^{32,90} Lateral condyle fractures are classified by the Milch system into 2 types based on the location of the fracture line.^{32,89,90} Milch type I fractures occur when the fracture line is lateral to the trochlear groove or in the trochlear groove. Milch type II fractures extend medial to the trochlea, allowing lateral subluxation of the ulna and elbow instability. Proper classification in children may be difficult to assess because the trochlea is not ossified until the child is approximately 10 years old.⁹⁰

Lateral condyle fractures with less than a 2-mm displacement may be treated nonoperatively with immobilization, if fracture healing is monitored.^{32,83} For fractures displaced more than 2 mm, surgery is recommended.^{83,89} Surgical treatment may involve open reduction and internal fixation^{14,89} or intraoperative arthrography followed by closed reduction and percutaneous pinning, with no consensus for the optimal technique in the literature.¹⁴ Complications following lateral condyle fractures may include delayed union, nonunion, avascular necrosis of the lateral condyle, and stiffness.^{32,89}

Medial Epicondyle Fractures

Medial epicondyle fractures account for 8% to 10% of pediatric elbow fractures⁸⁹ and are most common in children between the ages of 9 and 15 years.³² They are caused by a fall on an outstretched hand with forced wrist hyperextension and valgus stress at the elbow.⁸⁹ Associated elbow dislocation occurs in 50% of cases.⁸⁹ Possible complications to be aware of after medial epicondyle fractures include ulnar nerve irritation, elbow instability, non-union, and stiffness.

Fractures with displacement up to 2 mm can be treated with immobilization. Surgery is a consideration for fractures displaced greater than 2 mm.³² Farsetti et al⁴³ performed a long-term follow-up comparison of medial epicondyle fractures displaced greater than 5 mm treated surgically versus nonsurgically. Subjects were divided into 3 treatment groups: (a) nonsurgical treatment consisting of immobilization, (b) open reduction and internal fixation of the fragment, and (c) excision of the osteocartilaginous fragment.

Outcome measures included ROM, forearm muscle atrophy, elbow stability, grip strength, radiographs to assess epicondylar nonunion and posttraumatic arthritis, and electromyography if symptoms of nerve impairment were present. At an average follow-up of 34 years (range: 18 to 48 years), results showed patients treated with cast immobilization and patients treated with open reduction and internal fixation had similar functional outcomes, despite a high incidence of nonunion of the medial epicondyle in patients treated with cast immobilization only. A good functional outcome was defined as full or minimally restricted pain-free elbow motion, stable manual valgus stress testing, normal ipsilateral grip strength, minimal-to-no forearm muscle atrophy, and no radiographic signs of osteoarthritis. Good results were found in 16 of 19 patients in the immobilization group and in 15 of 17 patients following open reduction internal fixation. No good results were found in patients treated with excision of the epicondylar fragment. Because of poor long-term outcomes, surgical excision of the medial epicondyle should be avoided. Nonunion did not have negative effects on function. A study by Lee et al⁸⁵ also showed good to excellent results in subjects ages 7 to 17 years who had sustained medial epicondyle fractures (with greater than 5 mm displacement) that were treated operatively.

Radial Head and Neck Fractures

Radial head and neck fractures occur secondary to a fall on an outstretched hand with valgus stress.^{32,89} Treatment is determined by the amount of displacement and angulation between the radial head and shaft. Nondisplaced fractures usually have no residual deficits despite minimal treatment. It has also been shown that displaced Mason type I radial head or neck fractures have good long-term outcomes with conservative treatment.⁵⁸ Sanchez-Sotelo¹¹⁹ recommends nonoperative treatment for radial head fractures in adults with less than 2 mm displacement, less than 30% involvement of the articular surface, angulation of less than 30 degrees, and no instability. An angulation of 30 degrees or greater may be an indication for surgical consideration.⁸⁹ When treating displaced or comminuted radial head fractures, the clinician should be aware of possible associated injuries, including osteochondral and ligamentous injury.⁶³ Following radial fractures, complications may include malunion, radial head overgrowth, avascular necrosis, and nonunion.⁸⁹

Rehabilitation Concerns

Strategies to Regain Elbow Range of Motion Following Immobilization

The amount and rate of progression of rehabilitation following an elbow fracture is determined by several factors, including severity of injury, length of immobilization, concomitant injuries, age of patient, and level of sport activities. The primary focus of rehabilitation is on optimizing the return of elbow ROM and strength, with progression to functional daily and sport activities as needed.

Elbow ROM may not be completely regained following traumatic injury. Decreased ROM may be because of osseous structures, but is usually a result of the joint capsule or soft-tissue structures (muscles, tendons, ligaments). The viscoelastic properties of soft tissue must be considered during treatment to regain elbow ROM. These properties include strain rate dependency, creep, stress relaxation, elastic deformation, and plastic deformation. Strain rate is the dependence of material properties on the rate or speed in which a load is applied. Rapidly applied forces will cause stiffness and elastic deformation whereas gradually applied forces will result in plastic deformation.

Creep is defined as the continued deformation of soft tissue with the application of a fixed load (eg, traction and dynamic splinting). Stress relaxation is the reduction of forces, over time, in a material that is stretched and held at a constant length (eg, serial casting and static splinting). Elastic deformation is the elongation produced by loading that is recovered



Figure 21-26 Posterior glide of the ulnohumeral joint

after the load is removed. There is no long-term effect on tissues. Plastic deformation is the elongation produced under loading that will remain after the removal of a load, resulting in a permanent increase in length.¹⁶

A study by Bonutti et al¹⁶ evaluated the effectiveness of a patient-directed static progressive stretching program in the treatment of elbow contractures. Subjects had elbow contractures for 1 month to 42 years that did not respond to previous treatment consisting of physical therapy, dynamic splinting, serial casting, surgery, or a combination of these treatments. The orthosis providing a static progressive stretch was worn for 30 minutes with the patient increasing the amount of stretch every 5 minutes as tolerated. Separate 30-minute sessions were used in patients requiring flexion and extension improvement. Results showed an average improvement of 17 degrees extension and 14 degrees flexion. Improved results were seen in 4 to 6 weeks, with continued improvement in patients using the orthotic 3 months or more. There was no change in ROM in

patients 1 year after discontinuation of the orthosis, suggesting that the plastic deformation of soft tissue occurred and the elongation of tissue was maintained over time.

Manual rehabilitation techniques for improving elbow ROM include passive ROM and joint mobilizations. Passive range is performed in elbow flexion, extension, supination, and pronation. Care should be taken with passive ROM into extension, as end range stretching of the flexors can potentially contribute to heterotrophic ossification, as discussed previously. Elbow joint mobilizations may be used to restore joint arthrokinematics. Joint distraction (see Figure 21-18), posterior glides of the ulna (Figure 21-26), medial and lateral ulna glides (Figure 21-27), radial distraction (Figure 21-28), and dorsal and ventral glides of the proximal radioulnar (Figure 21-29) joint are used to increase elbow ROM.³⁷ Shoulder passive ROM should also be performed early in the rehabilitation process to prevent glenohumeral capsular hypomobility, especially if the injury required prolonged immobilization.



Figure 21-27 Lateral and medial glides of the ulnohumeral joint

A. Lateral glide. B. Medial glide.



Figure 21-28 Radial distraction mobilization



Figure 21-29 Dorsal and ventral glides of the proximal radioulnar joint

Pediatric Considerations

When diagnosing and treating pediatric elbow injuries, consideration must be given to bone maturation and growth. In young children, the elbow joint is cartilaginous with the appearance of apophyseal ossification centers between the ages of 2 and 10 years. It is important to be aware of the apophyseal ossification centers at the elbow so that they are not misinterpreted as fractures on a radiograph. The ossification centers with the date of appearance in parentheses include the capitellum (2 years), radial head (4 years), medial epicondyle (5 years), trochlea (7 years), olecranon (9 years), and lateral epicondyle (10 years).³² Because the soft tissues surrounding the apophyses are stronger than the cartilage present at the apophyses, injurious forces causing a sprain or strain in an adult may cause an avulsion fracture in children. The most common site for an avulsion fracture is the medial epicondyle. Medial epicondyle avulsion fractures occur in young throwing athletes due to an acute valgus stress and flexorpronator muscle contraction.⁵⁹ There is an acute onset of medial elbow pain after forceful contraction such as during a baseball pitch. The avulsion commonly occurs during late cocking or early acceleration phase of throwing. A "pop" may be heard at time of injury. If a medial epicondyle avulsion fracture is suspected, it is important to assess the ulnar nerve, point tenderness of the medial epicondyle, swelling, ecchymosis, and valgus instability.

The Salter-Harris classification system¹¹⁸ is commonly used to describe acute physeal injuries (Figure 21-30). There are 5 types of fractures in this classification, with type II fractures being the most common. Type I fractures occur when the epiphysis separates completely from the metaphysis. The mechanism of injury involves shear, torsion, and avulsion forces. Treatment consists of casting with excellent prognosis unless vascular damage is present. In a type II fracture, the fracture line extends along the growth plate and into the metaphysis. The triangular-shaped metaphyseal fragment is referred to as the Thurston-Holland sign. Type III fractures are intraarticular and extend from the joint surface to the weak zone of the growth plate and reaches the periphery of the plate. There is good prognosis with proper reduction and intact vascular supply. Surgery may be needed for type III fractures. Type IV fractures are characterized by the fracture extending from the joint surface through the epiphysis, across the full thickness of the growth plate, and through a portion of the metaphysis. Surgery is required for this type of fracture, and there is usually a poor prognosis unless the growth plate is completely and accurately aligned. A type V fracture is rare and involves crushing of the growth plate, which inhibits further growth.





A. Type I. B. Type II. C. Type III. D. Type IV. E. Type V.

Similar to elbow fractures in adults, treatment of pediatric elbow fractures varies based on location and type of fracture. Protection of the open growth plates is an important consideration to optimize long-term outcomes. Prolonged immobilization following injury can be more conservative in children than adults, as children do not develop the amount of stiffness and soft-tissue contractures as adults. Pediatric injuries may require less rehabilitation as a result of decreased ROM restriction when compared to adults.

Appendix 1: Postoperative Protocol for Elbow Arthroscopy and Removal of Loose Bodies

Acute Phase

Primary goals

- 1. Reduce pain and postoperative edema
- 2. Regain joint ROM and muscle length
- 3. Initiate submaximal resistive exercise as tolerated

Postoperative Days 1 and 2

- 1. Removal of bulky postoperative dressing and replacement with Ace wrap.
- 2. Electric stimulation and ice to decrease pain/inflammation.
- 3. Initiation of ROM exercise for the glenohumeral joint, elbow, forearm, and wrist.
- 4. Initiation of submaximal strengthening exercises including:
 - a. putty
 - b. isometric elbow and wrist flexion/extension
 - c. isometric forearm pronation/supination

Postoperative Days 2 to 7

- 1. ROM and joint mobilization to terminal ranges for the elbow, forearm, and wrist (avoid overaggressive elbow extension passive ROM)
- **2.** Begin progressive resistance exercise program with 0 to 1 lb weight and 3 sets of 15 repetitions
 - a. wrist flexion curls
 - b. wrist extension curls
 - c. radial deviation
 - d. ulnar deviation
 - e. forearm pronation
 - **f.** forearm supination
- 3. Upper body ergometer

Intermediate Phase

Primary goals

- 1. Begin total-arm strength-training program
- 2. Emphasize full elbow ROM

Postoperative 1 to 3 Weeks

- 1. Continue progressive resistance exercise program adding:
 - a. elbow extension
 - **b.** elbow flexion
 - c. isolated rotator cuff program (Jobe exercises)

37

- d. seated row
- e. manual and isotonic scapular program
- f. closed-chain, upper-extremity program

Advanced/Return to Activity Phase

Primary goals

- 1. Advance strengthening progression of distal upper extremity
- **2.** Prepare patient for return to functional activity with simulation of joint angles and muscular demands inherent in intended sport activity

Postoperative 4 to 8 Weeks

- 1. Isokinetic exercise introduction using wrist flexion/extension and forearm pronation/ supination movement patterns
- 2. Upper-extremity plyometrics with medicine balls
- 3. Isokinetic test to formally assess distal strength
- 4. Interval sport return program
 - a. criterion for advancement:
 - i. full, pain-free ROM
 - ii. 85% to 100% return of muscle strength
 - iii. no provocation of pain on clinical exam
- 5. Upper-extremity strength and flexibility maintenance program

AQ7

Appendix 2: Postoperative Rehabilitation Following Ulnar Collateral Ligament Reconstruction Using Autogenous Graft

Postoperative Week 1

Brace

• Posterior splint applied immediately postoperatively with elbow placed in 90 degrees of flexion. Progression to hinged ROM brace dependent on patient tolerance. ROM brace to remain locked at 90 degrees for week 1.

Rehab

- Modalities to decrease elbow swelling and control pain.
- ROM forearm pronation/supination and wrist flexion/extension.
- ROM glenohumeral joint and scapulothoracic joint mobilization.
- Shoulder isometrics (no internal rotation or external rotation as a result of valgus stress on elbow).
- Gripping exercises with balls or putty.

Postoperative Week 2

Brace

• ROM set in hinged elbow brace from 30-100 degrees.

39

Rehab

- Continue with above exercises and ROM.
- Initiate isometric muscular work of wrist flexion/extension, radial/ulnar deviation, and elbow flexion/extension within ROM available at ulnohumeral joint.
- Initiate closed-chain exercise over Swiss balls (wax-on/off) with limited weight bearing over extremity.
- Begin scapular protraction/retraction manual resistance in side-lying with the elbow in 90 degrees of elbow flexion.

Postoperative Week 3

Brace

• Hinged elbow brace is opened to 15 to 110 degrees. (ROM in brace is gradually increased 5 degrees in extension and 10 degrees in flexion each week unless otherwise specified by physician.)

Rehab

• No changes in exercises during this time period.

Postoperative Weeks 4 to 5

Brace

• Hinged elbow brace set at 10 degrees-120 degrees.

Rehab

- Begin submaximal isotonic exercise for wrist flexion/extension, radial/ulnar deviation and forearm pronation/supination with light 1-lb weight or Thera tubing (yellow or red).
- Begin shoulder isotonic exercise program with prone extension, prone horizontal abduction and standing scaption to 80 degrees elevation as tolerated. Continue to avoid rotational strengthening patterns, due to valgus stress at ulnohumeral joint. Weight attachment proximal to elbow with cuff weights recommended for introduction.
- Initiate seated rowing using Thera tube or machine/cables.

Postoperative Week 6

Brace*

• Hinged elbow brace set at 0 to 130 degrees.

Rehab

AQ4

- Begin elbow flexion/extension isotonics using available ranges and avoiding a "bounce home" type movement at end range extension.
- Initiate shoulder internal rotation and external rotation patterns using both isotonic machine or cables (submax), Thera tube (yellow or red to start), and initiation of side-lying external rotation pattern.
- Begin ball dribbling off ground using Swiss balls, Body Blade, Thera-Band resistance bar oscillation, and BOING using patterns of radial/ulnar deviation and pronation/ supination with varied shoulder positions less than 90 degrees of elevation.

^{*}Discontinuation of hinged elbow brace occurs between 6 and 10 weeks postoperative, as designated by referring physician.

Postoperative Weeks 10 to 12

Rehab

- Plyometric program initiated using Swiss ball, progressing to medicine ball. Patterns consisting of initially a 2-hand chest pass and progressing to side throws, wood chops, and eventually eccentric arm deceleration with contralateral arm throwing.
- Continuation of shoulder, elbow, forearm, and wrist isotonics.
- Rhythmic stabilization techniques using both open- and closed-chain environments.
- Closed-chain step-up progression.

Postoperative Week 12

Rehab

- Initiation of isokinetic training using the pattern of wrist flexion/extension at speeds ranging from 180 to 300 degrees per second. ROM stops used at 0 to 35 degrees wrist extension and 0 to 55 degrees wrist flexion. Upon successful completion of wrist flexion/extension during several trial treatments, isokinetic forearm pronation and supination is initiated using ROM stops of 0 to 50 degrees of pronation and supination.
- Shoulder isokinetic internal rotation/external rotation is initiated submaximally using speeds between 210 degrees and 300 degrees per second in the modified base position.

Postoperative Week 14 (Return to Activity Phase)

Rehab

- Initiation of elbow extension/flexion isokinetics using speeds between 180 degrees and 300 degrees per second and ROM stops at 10 degrees extension and 125 degrees flexion.
- Initiation of interval sport return programs.
- Continuation of upper-extremity strengthening programs and maintenance of particularly elbow extension ROM.
- A return to competitive levels of throwing or racquet sports is not expected until at least 6 months following surgery.

SUMMARY

- 1. The elbow joint is composed of the humeroulnar joint, humeroradial joint, and the proximal radioulnar joint. Motions in the elbow complex include flexion, extension, pronation, and supination.
- **2.** Fractures in the elbow may occur from a direct blow or falling on an outstretched hand. They may be treated by casting or in some cases by surgical reduction and fixation. Following surgical fixation, the patient may require 12 weeks for rehabilitation.
- **3.** Valgus extension overload injuries occur during the acceleration phase of the throwing motion and can result in the development of posterior medical osteophytes and loose bodies in the athletic elbow. Treatment via arthroscopy is followed by early immediate ROM and a progression of strength and functional training to restore full function to the elbow.

- **4.** The ulnar collateral ligament is injured as a result of a repetitive valgus force. Reconstruction is vital to competitive throwing patients.
- **5.** Elbow dislocations result from elbow hyperextension from a fall on an extended arm, with the radius and ulna dislocating posteriorly. The degree of stability present determines the course of rehabilitation. If the elbow is stable, a brief period of immobilization is followed by rehabilitation. An unstable dislocation requires surgical repair and thus a longer period of immobilization.
- **6.** Medial epicondylitis results from repetitive microtrauma to the common flexor and pronator tendons during pronation and flexion of the forearm and wrist.
- **7.** Lateral epicondylitis (tennis elbow) occurs with concentric or eccentric overload of the wrist extensors and supinators, most commonly the extensor carpi radialis brevis tendon.

REFERENCES

- 1. Adelsberg S. An EMG analysis of selected muscles with rackets of increasing grip size. *Am J Sports Med.* 1986;14:139-142.
- AQ8 **2.** An KN, Morrey BF. Biomechanics of the elbow. In: Morrey BF, ed. *The Elbow and Its Disorders*. Philadelphia, PA: Saunders; 1993.
 - Andrews JR, Heggland EJH, Fleisig GS, Zheng N. Relationship of ulnar collateral ligament strain to amount of medial olecranon osteotomy. *Am J Sports Med.* 2001;29(6):716-721.
 - Andrews JR, Soffer SR. *Elbow Arthroscopy*. St. Louis, MO: Mosby-Yearbook; 1994.
 - Andrews JR, Timmerman LA. Outcome of elbow surgery in professional baseball players. *Am J Sports Med.* 1995;23:407-4134.
 - **6.** Andrews JR, Wilk KE, Groh G. Elbow rehabilitation. In: Brotzman SB, ed. *Clinical Orthopaedic Rehabilitation*. Philadelphia, PA: Mosby-Yearbook; 1996:67-71.
 - 7. Andrews JR, Wilk KE, Satterwhite YE, Tedder JL. Physical examination of the thrower's elbow. *J Orthop Sports Phys Ther.* 1993;6:296-304.
 - **8.** Arnoczky SP, Delos D, Rodeo SA. What is platelet-rich plasma? *Oper Tech Sports Med.* 2011;19:142-148.
 - **9.** Ballentyne BT, O'Hare SJ, Paschall JL, et al. Electromyographic activity of selected shoulder muscles in commonly used therapeutic exercises. *Phys Ther.* 1993;73:668-682.
 - Basford JR, Sheffield CG, Cieslak KR. Laser therapy: a randomized, controlled trial of the effects of low intensity Nd:YAG laser irradiation on lateral epicondylitis. *Arch Phys Med Rehabil.* 2000;81:1504-1510.
 - 11. Bennett GE. Elbow and shoulder lesions of baseball players. *Am J Surg.* 1959;98:484-492.
 - **12.** Bennett JB, Green MS, Tullos HS. Surgical management of chronic medial elbow instability. *Clin Orthop Relat Res.* 1992;278:62-68.

- **13.** Bernhang AM, Dehner W, Fogarty C. Tennis elbow: a biomechanical approach. *Am J Sports Med.* 1974;2:235-260.
- **14.** Bhandari M, Tornetta P, Swiontkowski MF. Displaced lateral condyle fractures of the distal humerus. *J Orthop Trauma*. 2003;17:306-308.
- **15.** Blackburn TA, McLeod WD, White B, et al. EMG analysis of posterior rotator cuff exercises. *Athl Train*. 1990;25:40-45.
- **16.** Bonutti PM, Windau JE, Ables BA, Miller BG. Static progressive stretch to reestablish elbow range of motion. *Clin Orthop Relat Res.* 1994;303:128-134.
- Bowling RW, Rockar PA. The elbow complex. In: Davies GJ, Gould JA, eds. Orthopaedic and Sports Physical Therapy. St. Louis, MO: Mosby; 1985:476-496.
- Boyer MI, Hastings H. Lateral tennis elbow: is there any science out there? J Shoulder Elbow Surg. 1999;8:481-491.
- **19.** Brattberg G. Acupuncture therapy for tennis elbow. *Pain.* 1983;16:285-288.
- **20.** Carroll R. Tennis elbow: incidence in local league players. *Br J Sports Med.* 1981;15:250-255.
- **21.** Chinn CJ, Priest JD, Kent BE. Upper extremity range of motion, grip strength, and girth in highly skilled tennis players. *Phys Ther.* 1974;54:474-482.
- **22.** Conway JE, Jobe FW, Glousman RE, Pink M. Medial instability of the elbow in throwing athletes. *J Bone Joint Surg Am.* 1992;74(1):67-83.
- **23.** Creaney L, Wallace A, Curtis M, Connell D: Growth factor-based therapies provide additional benefit beyond physical therapy in resistant elbow tendinopathy: a prospective, single-blind, randomised trial of autologous blood injections versus platelet-rich plasma injections. *Br J Sports Med.* 2011;45:966-971.
- **24.** Croisier JL, Foidart-Dessalle, M, Tinant, F, et.al. An isokinetic eccentric programme for the management of chronic lateral epicondylar tendinopathy. *Br J Sports Med.* 2007;41:269-275.

42 Chapter 21 Rehabilitation of the Elbow

- **25.** Cyriax JH, Cyriax PJ. *Illustrated Manual of Orthopaedic Medicine*. London, UK: Butterworths; 1983.
- **26.** Davidson PA, Pink M, Perry J, Jobe FW. Functional anatomy of the flexor pronator muscle group in relation to the medial collateral ligament of the elbow. *Am J Sports Med.* 1995;23(2):245-250.
- **27.** de las Heras J, Duran D, de la Cerdo J, Romanillos O, Martinez-Miranda J, Rodriguez-Merchain EC. Supracondylar fractures of the humerus in children. *Clin Orthop Relat Res.* 2005;432:57-64.
- **28.** De Vos RJ, Weir A, Van Schie HTM, Bierma-Zeinstra R, Verhaar J Weinans H, Tol JL. Platelet-rich plasma injection for chronic Achilles tendinopathy. *JAMA*. 2010;303:144-149.
- **29.** DeLong JM, Russell RP, Mazzocca AD: Platelet-rich plasma: the PAW classification system. *Arthroscopy*. 2012;28:998-1009.
- **30.** Dijs H, Mortier G, Driessens M, DeRidder A, Willems J, Devroey TA. Retrospective study of the conservative treatment of tennis elbow. *Acta Belg Med Phys.* 1990;13:73-77.
- **31.** Dines JS, Frank JB, Akerman M, et al: Glenohumeral internal rotation deficits in baseball players with ulnar collateral ligament deficiency. *Am J Sports Med.* 2009;37(3):566-70.
- **32.** Do T, Herrara-Soto J. Elbow injuries in children. *Curr Opin Pediatr.* 2003;15:68-73.
- **33.** Ellenbecker TS. Rehabilitation of shoulder and elbow injuries in tennis players. *Clin Sports Med.* 1995;14:87-110.
- **34.** Ellenbecker TS. A total arm strength isokinetic profile of highly skilled tennis players. *Isokinet Exerc Sci.* 1991;1:9-21.
- **35.** Ellenbecker TS, Davies GJ. *Closed Kinetic Chain Exercise*. Champaign, IL: Human Kinetics; 2001.
- **36.** Ellenbecker TS, Davies GJ, Rowinski MJ. Concentric versus eccentric isokinetic strengthening of the rotator cuff: objective testing versus functional test. *Am J Sports Med.* 1988;16(1):64-69.
- **37.** Ellenbecker TS, Mattalino AJ. *The Elbow in Sport*. Champaign, IL: Human Kinetics; 1997.
- **38.** Ellenbecker TS, Mattalino AJ, Elam EA, Caplinger RA. Medial elbow laxity in professional baseball pitchers: a bilateral comparison using stress radiography. *Am J Sports Med.* 1998;26(3):420-424.
- **39.** Ellenbecker TS, Roetert EP. Isokinetic profile of elbow flexion and extension strength in elite junior tennis players. *J Orthop Sports Phys Ther.* 2003;33(2):79-84.
- **40.** Ellenbecker TS, Roetert EP. *Isokinetic Profile of Wrist and Forearm Strength in Female Elite Junior Tennis Players*. Platform presentation presented at the APTA Annual Conference and Exposition, Washington DC, June, 2003.
- **41.** Ellenbecker TS, Roetert EP. Unpublished data from the USTA on range of motion of the elbow and wrist in senior tennis players; 1994.

- **42.** Ellenbecker TS, Roetert EP, Bailie DS, Davies GJ, Brown SW. Glenohumeral joint total rotation range of motion in elite tennis players and baseball pitchers. *Med Sci Sports Exerc.* 2002;34(12):2052-2056.
- **43.** Farsetti P, Potenza V, Caterini R, Ippolito E. Longterm results of treatment of fractures of the medial humeral epicondyle in children. *J Bone Joint Surg Am.* 2001;83(9):1299-1305.
- **44.** Ficek K, Kamiński T, Wach E, Cholewiński J. Application of platelet rich plasma in sports medicine. *J Hum Kinet*. 2011;30:85-97.
- **45.** Fleck SJ, Kraemer WJ. *Designing Resistance Training Programs*. Champaign, IL: Human Kinetics; 1987.
- **46.** Gam AN, Warming S, Larsen LH, et al. Treatment of myofascial trigger points with ultrasound combined with massage and exercise. A randomized controlled trial. *Pain.* 1998;77(1):73-79.
- **47.** Glousman RE, Barron J, Jobe FW, et al. An electromyographic analysis of the elbow in normal and injured pitchers with medial collateral ligament insufficiency. *Am J Sports Med.* 1992;20:311-317.
- **48.** Goldie I. Epicondylitis lateralis humeri. *Acta Chir Scand Suppl.* 1964;339:1-114.
- **49.** Gosens T, Peerbooms JC, Van Laar W, Den Oudsten B. A double-blind randomized controlled trial with 2-year follow-up: ongoing positive effect of platelet-rich plasma versus corticosteroid injection in lateral epicondylitis. *Am J Sports Med.* 2011;39:1200-1208.
- 50. Gould JA, Davies GJ. Orthopaedic and sports rehabilitation concepts. In: Gould JA, Davies GJ, eds. Orthopaedic and Sports Physical Therapy. St. Louis, MO: Mosby, 1985:181-198.
- **51.** Greenbaum B, Itamura J, Vangsness CT, Tibone J, Atkinson R. Extensor carpi radialis brevis. *J Bone Joint Surg Br.* 1999;81(5):926-929.
- **52.** Groppel JL, Nirschl RP. A biomechanical and electromyographical analysis of the effects of counter force braces on the tennis player. *Am J Sports Med.* 1986;14:195-200.
- **53.** Guerra JJ, Timmerman LA. Clinical anatomy, histology, and pathomechanics of the elbow in sports. *Oper Tech Sports Med.* 1996;4:69-76.
- **54.** Haake M, Konig IR, Decker T, et al. Extracorporeal shock wave therapy in the treatment of lateral epicondylitis: a randomized multicenter trial. *J Bone Joint Surg Am.* 2002;84:1982-1991.
- **55.** Hang YS, Peng SM. An epidemiological study of upper extremity injury in tennis players with particular reference to tennis elbow. *J Formos Med Assoc*. 1984;83:307-316.
- 56. Harrelson GL, Leaver-Dunn D. Elbow rehabilitation. In: Andrews JR, Harrelson GL, Wilk KE, eds. *Physical Rehabilitation of the Injured Athlete*. 2nd ed. Philadelphia, PA: Saunders, 1998:554-588.
- 57. Hawkins RJ, Kennedy JC. Impingement syndrome in athletes. *Am J Sports Med.* 1980;8:151-158.

- 58. Herbertson P, Josefsson PO, Hasserius R, Karlsson C, Besjakov J, Karlsson MK. Displaced mason type I fractures of the radial head and neck in adults: a fifteen-to thirty-three-year follow-up study. *J Shoulder Elbow Surg.* 2005;14:73-77.
- **59.** Hughes PE, Paletta GA. Little leaguer's elbow, medial epicondyle injury, and osteochondritis dissecans. *Sports Med Arthroscopy Rev.* 2003;11:30-39.
- **60.** Indelicato PA, Jobe FW, Kerlan RK, Carter VS, Shields CL, Lombardo SJ. Correctable elbow lesions in professional baseball players: a review of 25 cases. *Am J Sports Med.* 1979;7:72-75.
- **61.** Ingham K. Transverse cross friction massage. *Phys Sportsmed.* 1981;9(10):116.
- **62.** Inman VT, Saunders JB de CM, Abbot LC. Observations on the function of the shoulder joint. *J Bone Joint Surg Am.* 1944;26:1-30.
- **63.** Itamura J, Roidis N, Mirzayan R, Vaishnzv S, Learch T, Shean C. Radial head fractures: MRI evaluation of associated injuries. *J Shoulder Elbow Surg.* 2005;14:421-424.
- **64.** Izumi T, Aoki M, Muraki T, Hidaka E. Stretching positions of the posterior capsule of the glenohumeral joint. *Am J Sports Med.* 2008;36(10):2014-2022.
- **65.** Jensen BR, Sjogaard G, Bornmyr S, Arborelius M, Jorgensen K. Intramuscular laser-Doppler flowmetry in the supraspinatus muscle during isometric contractions. *Eur J Appl Physiol Occup Physiol*. 1995;71(4):373-378.
- **66.** Jobe FW, Elattrache NS. Diagnosis and treatment of ulnar collateral ligament injuries in athletes. In: Morrey BF, ed. *The Elbow and its Disorders*. 2nd ed. Philadelphia, PA: Saunders, 1993:566-572.
- **67.** Jobe FW, Kvitne RS. Shoulder pain in the overhand or throwing athlete: the relationship of anterior instability and rotator cuff impingement. *Orthop Rev.* 1989;28(9):963-975.
- **68.** Jobe FW, Stark H, Lombardo SJ. Reconstruction of the ulnar collateral ligament in athletes. *J Bone Joint Surg Am.* 1986;68:1158-1163.
- **69.** Josefsson PO, Nilsson BE. Incidence of elbow dislocations. *Acta Orthop Scand.* 1986;57:537-538.
- **70.** Joyce ME, Jelsma RD, Andrews JR. Throwing injuries to the elbow. *Sports Med Arthroscopy Rev.* 1995;3:224-236.
- **71.** Kamien M. A rational management of tennis elbow. *Sports Med.* 1990;9:173-191.
- **72.** Keppler P, Salem K, Schwarting B, Kintzl L. The effectiveness of physiotherapy after operative treatment of supracondylar humeral fractures in children. *J Pediatr Orthop.* 2005;25:314-316.
- **73.** Kibler WB. The role of the scapula in athletic shoulder function. *Am J Sports Med.* 1998;26(2):325-337.
- **74.** Kibler WB. Role of the scapula in the overhead throwing motion. *Contemp Orthop.* 1991;22(5):525-532.
- **75.** Kibler WB, Chandler TJ, Livingston BP, Roetert EP. Shoulder range of motion in elite tennis players. *Am J Sports Med.* 1996;24(3):279-285.

- **76.** Kibler WB, Uhl TL, Maddux JWQ, Brooks PV, Zeller B, McMullen J. Qualitative clinical evaluation of scapular dysfunction: a reliability study. *J Shoulder Elbow Surg.* 2002;11:550-556.
- **77.** King JW, Brelsford HJ, Tullos HS. Analysis of the pitching arm of the professional baseball pitcher. *Clin Orthop.* 1969;67:116-123.
- **78.** Kitai E, Itay S, Ruder A, et al. Ann epidemiological study of lateral epicondylitis in amateur male players. *Ann Chir Main.* 1986;5:113-121.
- **79.** Kraushaar BS, Nirschl RP. Tendinosis of the elbow (tennis elbow). Clinical features and findings of histopathological, immunohistochemical and electron microscopy studies. *J Bone Joint Surgery Am.* 1999;81:259-278.
- **80.** Kulund DN, Rockwell DA, Brubaker CE. The long term effects of playing tennis. *Phys Sportsmed.* 1979;7:87-92.
- **81.** Kuroda S, Sakamaki K. Ulnar collateral ligament tears of the elbow joint. *Clin Orthop Relat Res.* 1986;208: 266-271.
- **82.** Labelle H, Guibert R, Joncas J, Newman N, Fallaha M, Rivard CH. Lack of scientific evidence for the treatment of lateral epicondylitis of the elbow. *J Bone Joint Surg Br.* 1992;74:646-651.
- **83.** Launay F, Leet A, Jacopin S, Jouve J, Bollini G, Sponseller PD. Lateral humeral condyle fractures in children: a comparison to two approaches in treatment. *J Pediatr Orthop.* 2004;24:385-391.
- **84.** Leadbetter WB. Cell matrix response in tendon injury. *Clin Sports Med.* 1992;11:533-579.
- **85.** Lee H, Shen H, Chang J, Lee C, Wu S. Operative treatment of displaced medial epicondyle fractures in children and adolescents. *J Shoulder Elbow Surg.* 2005;14:178-185.
- **86.** Linscheid RL, O'Driscoll SW. Elbow dislocation. In: Morrey BF, ed. *The Elbow and Its Disorders*. 2nd ed. Philadelphia, PA: Saunders, 1993:441-452.
- **87.** Magee DJ. Elbow. In: Magee DJ, ed. *Orthopedic Physical* AQ8 *Assessment*. Philadelphia, PA: Saunders; 1997.
- **88.** McFarland EG, Torpey BM, Carl LA. Evaluation of shoulder laxity. *Sports Med.* 1996;22:264-272.
- **89.** Milbrandt TA, Copley LA. Common elbow injuries in children: evaluation, treatment, and clinical outcomes. *Curr Opin Orthop.* 2004;15:286-294.
- **90.** Mirsky EC, Karas EH, Weiner L. Lateral condyle fractures in children: evaluation of classification and treatment. *J Orthop Trauma*. 1997;11(2):117-120.
- **91.** Mishra A, Pavelko T. Treatment of chronic elbow tendinosis with buffered platelet-rich plasma. *Am J Sports Med.* 2006;34:1774-1778.
- **92.** Morrey BF. *The Elbow and its Disorders*. 2nd ed. Philadelphia, PA: Saunders; 1993.
- **93.** Morrey BF, An KN. Articular and ligamentous contributions to the stability of the elbow joint. *Am J Sports Med.* 1983;11:315.
- **94.** Neer CS. Impingement lesions. *Clin Orthop.* 1973;173:70-77.

Chapter 21 Rehabilitation of the Elbow

- AQ9 **95.** Nirschl RP. In: Morrey BF, ed. *The Elbow and its Disorders*. 2nd ed. Philadelphia, PA: Saunders; 1993:537-552.
 - Nirschl RP. Elbow tendinosis/tennis elbow. *Clin Sports Med.* 1992;11:851-870.
 - **97.** Nirschl RP, Rodin DM, Ochiai DH, Maartmann-Moe C. Iontophoretic administration of dexamethasone sodium phosphate for acute epicondylitis: a randomized, doubleblinded, placebo controlled study. *Am J Sports Med.* 2003;31(2):189-195.
 - **98.** Nirschl R, Sobel J. Conservative treatment of tennis elbow. *Phys Sportsmed.* 1981;9:43-54.
 - **99.** O'Driscoll SW. Elbow instability. *Hand Clin.* 1994;10:405-415.
 - **100.** O'Driscoll SW, Morrey BF. Arthroscopy of the elbow. *J Bone Joint Surg Am.* 1992;74:84-94.
 - **101.** O'Driscoll SW, Lawton RL, Smith AM. The moving valgus stress test for medial ulnar collateral ligament tears of the elbow. *Am J Sports Med.* 2005;33(2):231-239.
 - **102.** Oglive-Harris DJ, Gordon R, MacKay M. Arthroscopic treatment for posterior impingement in degenerative arthritis of the elbow. *Arthroscopy*. 1995;11(4):437-443.
 - 103. Olsen BS, Sojbjerg JO, Dalstra M, Sneppen O. Kinematics of the lateral ligamentous constraints of the elbow joint. *J Shoulder Elbow Surg.* 1996;5:333-341.
 - 104. Omar AS, Ibrahim ME, Ahmed AS, Said M. Local injection of autologous platelet rich plasma and corticosteroid in treatment of lateral epicondylitis and plantar fasciitis: randomized clinical trial. *Egyptian Rheumatologist*. 2012;34:43-49.
 - **105.** Peerbooms JC, Sluimer J, Bruijn DJ, Gosens T. Positive effect of an autologous platelet concentrate in lateral epicondylitis in a double-blind randomized controlled trial: platelet-rich plasma versus corticosteroid injection with a 1-year follow-up. *Am J Sports Med.* 2010;38:255-262.
 - **106.** Percy EC, Carson JD. The use of DMSO in tennis elbow and rotator cuff tendinitis. A double blind study. *Med Sci Sports Exerc.* 1981;13:215-219.
 - 107. Peterson M, Butler S, Eriksson M, Svardsudd K. A randomized controlled trial of exercise versus wait-list in chronic tennis elbow (lateral epicondylosis). *Ups J Med Sci.* 2011;116(4):269-279.
 - **108.** Priest JD, Jones HH, Nagel DA. Elbow injuries in highly skilled tennis players. *J Sports Med.* 1974;2(3):137-149.
 - **109.** Priest JD, Jones HH, Tichenor CJC, et al. Arm and elbow changes in expert tennis players. *Minn Med.* 1977;60:399-404.
 - **110.** Reddy AS, Kvitne RS, Yocum LA, Elattrache NS, Glousman RE, Jobe FW. Arthroscopy of the elbow: A long term clinical review. *Arthroscopy*. 2000;16(6):588-594.
 - Regan WD, Korinek SL, Morrey BF, An KN. Biomechanical study of ligaments around the elbow joint. *Clin Orthop.* 1991;271:170-179.
 - **112.** Rhu KN, McCormick J, Jobe FW, et al. An electromyographic analysis of shoulder function in tennis players. *Am J Sports Med.* 1988;16:481-485.

- **113.** Rijke AM, Goitz HT, McCue FC. Stress radiography of the medial elbow ligaments. *Radiology*. 1994;191:213-216.
- **114.** Roetert EP, Ellenbecker TS, Brown SW. Shoulder internal and external rotation range of motion in nationally ranked junior tennis players: a longitudinal analysis. *J Strength Cond Res.* 2000;14(2):140-143.
- **115.** Rosenthal M. The efficacy of flurbiprofen versus piroxicam in the treatment of acute soft tissue rheumatism. *Curr Med Res Opin.* 1984;9:304-309.
- **116.** Ross G, McDevitt ER, Chronister R, et al. Treatment of simple elbow dislocation using an immediate motion protocol. *Am J Sports Med.* 1999;27(3):308-311.
- **117.** Runge F. Zur genese unt behand lung bes schreibekramp fes Berl Kun Woschenschr. 1873;10:245.
- **118.** Salter RB, Harris WR. Injuries involving the epiphyseal plate. *J Bone Joint Surg Am.* 1963;45:587-632.
- **119.** Sanchez-Sotelo J, Barwood SA, Blaine TA. Current concepts in elbow fracture care. *Curr Opin Orthop.* 2004;15:300-310.
- **120.** Sato D, Takahara M, Narita A, et al. Effect of platelet-rich plasma with fibrin matrix on healing of intrasynovial flexor tendons. *J Hand Surg Am.* 2012;37:1356-1363.
- **121.** Shanley E, Rauh MJ, Michener LA, Ellenbecker TS, Garrison JC, Thigpen CA. Shoulder range of motion measures as risk factors for shoulder and elbow injuries in high school softball and baseball players. *Am J Sports Med.* 2011;39:1997-2006.
- **122.** Skaggs DL, Mirzayan R. The posterior fat pad sign in association with occult fracture of the elbow in children. *J Bone Joint Surg Am.* 1999;10:1429-1433.
- **123.** Slocum DB. Classification of the elbow injuries from baseball pitching. *Am J Sports Med.* 1978;6:62.
- **124.** Smith R, Brunulli J. Shoulder kinesthesia after anterior glenohumeral dislocation. *Phys Ther.* 1989;69(2): 106-112.
- **125.** Stroyan M, Wilk KE. The functional anatomy of the elbow complex. *J Orthop Sports Phys Ther.* 1993;17:279-288.
- **126.** Sullivan PE, Markos PD, Minor MD. *An Integrated Approach to Therapeutic Exercise: Theory and Clinical Application*. Reston, VA: Reston Publishing; 1982.
- **127.** Svernl AB, Adolfsson L. Non-operative treatment regime including eccentric training for lateral humeral epicondylalgia. *Scand J Med Sci Sports.* 2001;11(6):328-334.
- **128.** Thanasas C, Papadimitriou G, Charalambidis C, Paraskevopoulos I, Papanikolaou A. Platelet-rich plasma versus autologous whole blood for the treatment of chronic lateral elbow epicondylitis: a randomized controlled clinical trial. *Am J Sports Med.* 2011;39:2130-2134.
- **129.** Tinsley BA, Ferreira JV, Dukas AG, Mazzocca AD. Platelet-rich plasma nonoperative injection therapy a review of indications and evidence. *Oper Tech Sports Med.* 2012;20:192-200.
- **130.** Townsend H, Jobe FW, Pink M, et al. Electromyographic analysis of the glenohumeral muscles during a

44

AQ10

baseball rehabilitation program. *Am J Sports Med.* 1991;19:264-272.

- **131.** Tullos HS, Ryan WJ. Functional anatomy of the elbow. In: Zarins B, Andres JR, Carson WD, eds. *Injuries to the Throwing Arm.* Philadelphia, PA: Saunders; 1985.
- **132.** Tyler TF, Thomas GC, Nicholas SJ, McHugh MP. Addition of isolated wrist extensor eccentric exercise to standard treatment for chronic lateral epicondylosis: a prospective randomized trial. *J Shoulder Elbow Surg.* 2010;19(6):917-922.
- **133.** Uhl TL. Uncomplicated elbow dislocation rehabilitation. *Athl Ther Today.* 2000;5(3):31-35.
- **134.** Uhl TL, Gould M, Gieck JH. Rehabilitation after posterolateral dislocation of the elbow in a collegiate football player: a case report. *J Athl Train.* 2000;35(1):108-110.
- **135.** Verhaar JAN, Walenkamp GHIM, Kester ADM, Linden AJVD. Local corticosteroid injection versus Cyriax-type physiotherapy for tennis elbow. *J Bone Joint Surg Br.* 1995;77:128-132.
- 136. Warfel JH. Muscles of the Arm. The Extremities, Muscles, and Motor Points. Philadelphia, PA: Lea & Febinger; 1993.
- **137.** Waslewski GL, Lund P, Chilvers M, Taljanovic M, Krupinski E. *MRI Evaluation of the Ulnar Collateral Ligament of the Elbow in Asymptomatic, Professional*

Baseball Players. Presented at the AOSSM Meeting, San Diego, CA; 2002.

- **138.** Wilk KE, Arrigo CA. Rehabilitation of elbow injuries. In: Andrews JR, Harrelson GL, Wilk KE, eds. *Physical Rehabilitation of the Injured Athlete*. **3**rd ed. Philadelphia, PA: Saunders, 2004:590-618.
- **139.** Wilk KE, Arrigo CA, Andrews JR. Rehabilitation of the elbow in the throwing athlete. *J Orthop Sports Phys Ther.* 1993;17:305-317.
- **140.** Wilk KE, Azar FM, Andrews JR. Conservative and operative rehabilitation of the elbow in sports. *Sports Med Arthroscopy Rev.* 1995;3:237-258.
- **141.** Wilk KE, Macrina LC, Fleisig GS, et al. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *Am J Sports Med.* 2011;39:329-335.
- 142. Wilson FD, Andrews JR, Blackburn TA, McCluskey G. Valgus extension overload in the pitching elbow. *Am J Sports Med.* 1983;11(2):83-88.
- **143.** Winge S, Jorgensen U, Nielsen AL. Epidemiology of injuries in Danish championship tennis. *Int J Sports Med.* 1989;10:368-371.
- **144.** Wolf BR, Altchek DW. Elbow problems in elite tennis players. *Tech Shoulder Elbow Surg.* 2003;4(2):55-68.

Author Query

- AQ1: Not clear as written. Do you mean "Andrews et al report that the valgus extension overpressure test determines whether . . . "?
- AQ2: Is tendonosis correct or should it be tendinosis? If the latter, please correct throughout chapter.
- AQ3: 1 kg = 2.2 lb. Rather than 1 kg, should it be 0.5 kg? If not, should you clarify why there is the weight discrepancy? Or perhaps delete "or 1 kg"?
- AQ4: Elsewhere in this chatper it was B.O.I.N.G. and boing. Which is the correct spelling?
- AQ5: Please review this sentence for clarity. I am unable to determine what is done when. A good deal of the clarity problem lies in the phrasing "is performed followed by".
- AQ6: Please identify where by section title.
- AQ7: Appendix 2 is not called out in the text. Please add a callout.
- AQ8: Please provide pages.
- AQ9: Please provide chapter title.
- AQ10: Need punctuation at end of article title.