Rehabilitation of the Elbow Following Sports Injury

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Injuries to the elbow occur frequently in the overhead athlete due to the repetitive loads and forceful muscular activations inherent in throwing, hitting, serving, and spiking.1,2 The most common injuries in the athlete include humeral epicondylitis, valgus extension overload, and ulnar collateral ligament injury.3,4 The initial upper extremity evaluation including radiographs is the critical first step in early recognition and diagnosis of elbow injury, and allows for the referral to physical therapy whereby a comprehensive rehabilitation program can be initiated. The purpose of this article is to review the common elbow injuries in the overhead athlete and clinical tests used to confirm them, in addition to providing key concepts in the rehabilitation programs used to treat individuals with elbow injury and return them to high-level overhead activity.

COMMON INJURIES IN THE ATHLETE’S ELBOW

One of the most common overuse injuries of the elbow is humeral epicondylitis.5,6 The repetitive overuse reported as one of the primary causative factors is particularly evident in the history of many athletic patients with elbow dysfunction. Epidemiologic research on adult tennis players reports incidences of humeral epicondylitis ranging from 35% to 50%.7–11 This incidence is actually far greater than that reported in elite junior players (11%–12%) (United States Tennis Association, unpublished data, 1992).12

Reported in the literature as early as 1873 by Runge,13 humeral epicondylitis or “tennis elbow” as it is more popularly known, has been extensively studied by many investigators. Cyriax,14 in 1936, listed 26 causes of tennis elbow, and an extensive study of this overuse disorder by Goldie15 in 1964 reported hypervascularization...
of the extensor aponeurosis and an increased quantity of free nerve endings in the subtendinous space. Leadbetter\textsuperscript{16} described humeral epicondylitis as a degenerative condition consisting of a time-dependent process including 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 in which an inflammatory response was considered as a primary factor, hence the term “tendinitis” was used as opposed to the term recommended by Leadbetter\textsuperscript{16} and Nirschl.\textsuperscript{17}

Nirschl\textsuperscript{4,6,17} and Nirschl and Ashman\textsuperscript{18} have defined humeral epicondylitis as an extra-articular tendonous injury characterized by excessive vascular granulation and an impaired healing response in the tendon, which they have termed “angiofibroblastic hyperplasia.” In a thorough histopathological analysis, Nirschl and colleagues\textsuperscript{19} studied specimens of injured tendon obtained from areas of chronic overuse and reported that they do not contain large numbers of lymphocytes, macrophages, and neutrophils. Instead, tendonosis seems to be a degenerative process characterized by large populations of fibroblasts, disorganized collagen, and vascular hyperplasia.\textsuperscript{19} 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. Nirschl\textsuperscript{17} has 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 communis.\textsuperscript{19} In addition, the extensor carpi radialis longus and extensor carpi ulnaris can be involved. The primary site of medial humeral epicondylitis is the flexor carpi radialis, pronator teres, and flexor carpi ulnaris tendons.\textsuperscript{6,17} Finally, Nirschl\textsuperscript{17} 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 (left arm in a right-handed golfer), whereas medial humeral epicondylitis is far more common in elite tennis players and throwing athletes, due to 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. In addition, the trailing arm of the golfer (right arm in a right-handed golfer) is reportedly more likely to have medial symptoms than lateral.

Repeated activities such as overhead throwing, tennis serving, or throwing the javelin can lead to characteristic patterns of osseous and osteochondral injury in the older active patient as well as the adolescent elbow. These injuries are commonly referred to as valgus extension overload injuries (Fig. 1).\textsuperscript{20} 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 body spurs or osteophytes at the medial epicondyle or coronoid process of the elbow.\textsuperscript{21–23} In addition, 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.\textsuperscript{20} The combined motion of valgus pressure with the powerful extension of the elbow leads to posterior osteophyte formation, due to impingement of the posterior medial aspect of the ulna against the trochlea and olecranon fossa. Joyce and colleagues\textsuperscript{24} have 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.\textsuperscript{22,25}

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 radiocapitellar joint. Of great concern
in the immature pediatric throwing athlete is osteochondritis dissecans (OCD) and Panner disease. Although the incidence of OCD and Panner disease is low, the importance of obtaining radiographs in the thorough evaluation of the pediatric elbow cannot be understated. The presence of OCD and Panner disease, though not common, should be ruled out in every case. The characteristics of Panner disease are for the presence of fissuring and increased density of the capitellum. The most common onset age of both Panner disease and OCD is less than 10 years, occurring most commonly in males, and typically in the dominant arm. In the older adult elbow, the radiocapitellar joint can be the site of joint degeneration and osteochondral injury from the compressive loading. This lateral compressive loading is increased in the elbow, with medial ulnar collateral ligament laxity or ligament injury.

SPECIAL CONSIDERATIONS FOR THE ADOLESCENT ATHLETE’S ELBOW

Injuries to the throwing arm in the adolescent athlete occur frequently due to the highly repetitive nature of baseball, tennis, and other overhead sports. The increased demands of early sport specialization and year-round participation required to obtain success and develop high levels of skill in these overhead sports can subject the adolescent’s shoulder and elbow to injury. A recent epidemiologic report studying youth sport participation and injury risk concluded that participation in several sports (multiple) seemed to have a protective effect from the harmful risks of single-sport participation. Despite these findings, clinicians frequently find extensive single-sport participation histories when evaluating young athletes with shoulder and elbow injury. This high participation can lead to extensive musculoskeletal adaptation and eventual injury. One of the primary unique concerns for any clinician working with the adolescent thrower with shoulder or elbow pain of overuse origin is the growth plate (Fig. 2). Knowledge of anatomic and developmental factors inherent in the adolescent’s upper extremity can guide clinicians during evaluation and treatment of overuse injuries. Repetitive valgus extension stresses applied to the young overhead athlete can lead to injury of the apophyseal growth plate (physes) in the elbow. Acute injury to the medial epicondylar apophysis can be in the form of an avulsion, with chronic

Fig. 1. Osteochondral injury from valgus extension overload mechanism of the overhead throwing motion.
stress leading to traction apophysitis. Apophyseal separation will occur in adolescents, instead of rupture of the ulnar collateral ligament. The cartilaginous growth plate represents the weak link, and before fusion of the secondary ossification center, strong forceful contraction of the flexor pronator musculature that occurs during the acceleration phase of the throwing motion or overhead serving motion in tennis can cause apophyseal separation. The growth plate is a cartilaginous disc between the apophysis and metaphysis of the bone. The site of separation of the growth plate is frequently between the calcified and uncalcified cartilage matrix. The relatively small amount of calcified matrix at this level accounts for the relative weakness of the growth plate, making the area vulnerable to injury with repeated stresses, particularly during the valgus stress coupled with extension at the elbow with overhead throwing.

Ossification centers of primary importance to the overhead throwing athlete are the medial epicondyle and olecranon ossification centers. The medial epicondyle ossification center is the second ossification center to appear at age 4 and develops slowly, and is the last center to unite with the humeral shaft, as late as 15 to 16 years of age. The olecranon ossification center usually develops at approximately 9 years of age and begins to unite at age 14. The high-intensity muscular contraction of the triceps, through its insertion on the olecranon during the acceleration of throwing and serving motions, may create problems in this important region. These osseous injuries further support standard radiography of the elbow during the comprehensive evaluation process, before commencement of a rehabilitation program. Additional ossification centers (with the date of appearance) include the capitellum (2 years), radial head (4 years), medial epicondyle (4 years), trochlea (7 years), olecranon (9 years), and lateral epicondyle (10 years). Because the soft tissue surrounding the apophyses is stronger than the cartilage present at the apophyses, injurious forces causing a sprain

Fig. 2. Growth plates of the human elbow with approximate time of closure.
or strain in an adult may cause an avulsion fracture in children. The most common site for an avulsion fracture is the medial epicondyle. The avulsion commonly occurs during the late cocking/early acceleration phase of throwing, when a pop may be heard at the time of injury. The Salter-Harris classification system is commonly used to describe acute physeal injuries. The reader is referred to this reference for a more complete discussion of this important classification.

**CLINICAL EXAMINATION OF THE ELBOW**

Structural inspection of the patient’s elbow must include a complete and thorough inspection of the entire upper extremity and trunk. The heavy reliance on the kinetic chain for power generation and the important role of the elbow as a link in the kinetic chain necessitates the examination of the entire upper extremity and trunk in the clinical evaluation. However, because many overuse injuries occur in athletic individuals, structural inspection of the patient or athlete with an injured elbow can be complicated by a lack of bilateral symmetry in the upper extremities. Adaptive changes are commonly encountered during clinical examination of the athletic elbow, particularly in the unilaterally dominant upper extremity athlete. In these 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. A brief overview of the common adaptations that have been reported in the literature can provide valuable information to assist the clinician during the structural inspection of the injured athlete with elbow pain.

Several classic studies have reported on elbow range of motion adaptations. King and colleagues initially reported on elbow range of motion in professional baseball pitchers. Fifty percent of the pitchers examined were found to have a flexion contracture of the dominant elbow, with 30% of subjects demonstrating a cubitus valgus deformity. Chinn and colleagues measured world-class professional adult tennis players and reported significant elbow flexion contractures on the dominant arm as well. More recently, Ellenbecker and colleagues measured elbow flexion contractures averaging $5^\circ$ in a population of 40 healthy professional baseball pitchers. Directly related to elbow function was wrist flexibility, which Ellenbecker and colleagues reported as significantly less in extension on the dominant arm due to tightness of the wrist flexor musculature, with no difference in wrist flexion range of motion between extremities. Wright and colleagues reported on 33 throwing athletes before the competitive season. The average loss of elbow extension was $7^\circ$ and the average loss of flexion was $5.5^\circ$. Ellenbecker and Roetert (Ellenbecker TS, Roetert EP, unpublished data, 1994) measured senior tennis players aged 55 years and older, and found flexion contractures averaging $10^\circ$ in the dominant elbow as well as significantly less wrist flexion range of motion. The higher use of the wrist extensor musculature is likely the cause of limited wrist flexor range of motion among the senior tennis players, as opposed to the reduced wrist extension range of motion from excessive overuse of the wrist flexor muscles inherent in baseball pitching.

Although it is beyond the scope of this article, it is imperative that glenohumeral joint rotational range of motion be measured due to the important role of glenohumeral internal rotation deficiency in valgus loading of the throwing elbow. For a complete discussion of glenohumeral joint rotational measurement with scapular stabilization, the reader is referred to these references. Identification of a loss of glenohumeral joint internal rotation and, more importantly, loss of total rotation range of motion with internal rotation range of motion loss would lead the clinician to interventions to...
address the proximal rotational deficiency in addition to providing proximal stabilization of the scapulothoracic and glenohumeral joints.

In summary, based on the findings of these descriptive profiles, the finding of an elbow flexion contracture and limited wrist flexion or extension range of motion, as well as reduced glenohumeral joint internal rotation, can be expected during the examination of an athlete from a unilaterally dominant upper extremity sport. Careful measurement during the clinical examination is recommended to determine baseline levels of range of motion loss in the distal upper extremity.

Several studies have also been published regarding osseous adaptations in the athletic elbow. In a study by Priest and colleagues, 42 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. In addition, Priest and colleagues reported 2 times as many bony adaptations, such as spurs, on the medial aspect of the elbow compared with the lateral aspect. The coronoid process of the ulna was the number 1 site of osseous adaptation or spurring. An average 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. In a magnetic resonance imaging (MRI) study, Waslewski and colleagues 43 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.

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 and colleagues 34 measured medial elbow joint laxity in 40 asymptomatic professional baseball pitchers, to determine whether 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 (kilo-Pascals) with the elbow placed in 25° of elbow flexion and the forearm in a supinated position. 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 and colleagues 44 using stress radiography had 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 and colleagues 34 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.

In addition to the range of motion and osseous adaptations, muscular adaptations occur. Isometric grip strength measured using a hand grip dynamometer has revealed unilateral increases in strength in elite junior, adult, and senior tennis players ranging from 10% to 30% using standardized measurement methods. 3,33,45,46 Isokinetic dynamometers have been used to measure specific muscular performance parameters in elite-level tennis players and baseball pitchers. 3,45,47,48

Ellenbecker 45 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 compared
with the nondominant extremity. In addition, 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. 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% compared with the nondominant extremity, with no difference in wrist extension strength or forearm supination strength between extremities. Wilk and colleagues 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 compared with the nondominant extremity.

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

ELBOW EXAMINATION SPECIAL TESTS

In addition to methods discussed in the previous section, including accurate measurement of both distal and proximal joint range of motion, radiographic screening, and muscular strength assessment, several other tests should be included in the comprehensive examination of the athletic elbow. Although it is beyond the scope of this article to completely review all of the necessary tests, several are highlighted based on their overall importance. The reader is referred to Morrey, Ellenbecker and Mattalino, and Magee for more complete articles solely on examination of the elbow.

Clinical testing of the joints proximal and distal to the elbow allows the examiner to rule out referral 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. Caution must therefore be used when basing the clinical diagnosis solely on this examination maneuver. The test is not sensitive but is specific for cervical radiculopathy, and can be used to help confirm a cervical radiculopathy.

In addition to clearing the cervical spine centrally, clearing the glenohumeral joint is important. Determining the presence of concomitant impingement or instability is also highly recommended. Use of the Sulcus sign to determine the presence of multidirectional instability of the glenohumeral joint, along with the subluxation/relocation sign and load and shift test, can provide valuable insight into the status of the glenohumeral joint. The impingement signs of Neer and Hawkins and Kennedy are also helpful in ruling out proximal tendon pathology.

In addition to the clearing tests for the glenohumeral joint, full inspection of the scapulothoracic joint is recommended. Clinical experience via observation noted by the authors of this article includes the high association of scapular and rotator cuff weakness with overuse elbow injury in athletes. The presence of overuse injuries in the elbow occurring with proximal injury to the shoulder complex or with scapulothoracic dysfunction is widely reported, and thus a thorough inspection of the
proximal joint is extremely important in the comprehensive management of elbow pathology.

Therefore, 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 and colleagues have recently presented a classification system for scapular pathology. Careful observation of the patient at rest and with the hands placed on 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. Bilateral comparison forms the primary basis for identifying scapular pathology; however, in many athletes bilateral scapular pathology can be observed.

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

The valgus stress test 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° of elbow flexion and forearm supination. The slight 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 position places a greater relative stress on the medial ulnar collateral ligament. 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 Grade I 0 to 5 mm, Grade II 5 to 10 mm, and Grade III greater than 10 mm. Use of greater than 25° of elbow flexion will increase the amount of humeral rotation during performance of the valgus stress test will transmit misleading information to the clinician’s hands. Safran and colleagues studied the effect of forearm rotation during performance of the valgus stress test of the elbow. These investigators found that laxity of the ulnohumeral joint was always greatest when the elbow was tested with the forearm in neutral rotation compared with either the fully pronated or supinated position.

The milking sign is a test the patient performs on himself, with the elbow in approximately 90° of elbow flexion (Fig. 3). 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.

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.

The valgus extension overpressure test has been reported by Andrews and colleagues to determine whether posterior elbow pain is caused by a posteromedial osteophyte abutting the medial margin of the trochlea and the olecranon fossa (Fig. 4). This test is performed by passively extending the elbow while maintaining a valgus stress to the elbow. 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.
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. 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 secondary to tendon degeneration. Reproduction of lateral or medial elbow pain with resistive muscle testing (provocation testing) may indicate concomitant tendon injury at the elbow, and would direct the clinician to perform a more complete elbow examination.

One of the more recent elbow special tests reported in the literature is the moving valgus test. This test is performed with the patient’s upper extremity in approximately 90° of abduction (Fig. 5). The elbow is maximally flexed, and a moderate valgus stress is imparted to the elbow to simulate the late cocking phase of the throwing motion. Maintaining the modest valgus stress at the elbow, the elbow is extended from the fully flexed position. A positive test for ulnar collateral ligament injury is confirmed when reproduction of the patient’s pain occurs and is maximal over the medial ulnar collateral ligament between 120° and 70° in what the investigators have termed the “shear angle” or pain zone. O’Driscoll and colleagues examined 21 athlete patients with a primary complaint of medial elbow pain from medial collateral ligament insufficiency or other valgus overload abnormality using the moving valgus test. The moving valgus test was found to be highly sensitive (100%) and specific (75%) when compared with arthroscopic exploration of the medial ulnar collateral ligament. The mean angle of maximum pain reproduction in this study was 90° of elbow flexion. This test can provide valuable clinical input during the evaluation of the patient with medial elbow pain.

These special examination techniques are unique to the elbow and, when combined with a thorough examination of the upper extremity kinetic chain and cervical spine, can result in an objectively based assessment of the patient’s pathology and enable the clinician to design a treatment plan based on the examination findings.
TREATMENT

The treatment of overuse elbow injuries such as humeral epicondylitis begins following the thorough evaluation and referral to physical therapy. Patients initially are treated to reduce pain, and increase range of motion, muscular strength, and overall function of the injured upper extremity. As mentioned earlier, the entire upper extremity kinetic chain is evaluated and is also integrated into the treatment process. For the purposes of this article, several key concepts are covered encompassing the treatment of the injured athlete’s elbow. These concepts include understanding the treatment basis for tendonitis versus tendonosis, a very important distinction for the treatment of humeral epicondylitis, as discussed earlier in this article. In addition, the important concepts of rotator cuff and scapular stabilization, often viewed as only applicable for the treatment of shoulder dysfunction, are outlined as they

Fig. 4. (A, B), Valgus extension overpressure test.
form an extremely important base for the treatment of the distal upper extremity. Finally, exercise progressions for the distal upper extremity and return to activity guidelines are discussed.

**Treatment of Tendonitis Versus Tendonosis**

Lateral epicondylitis represents a frequent overuse injury.\(^{66,67}\) Wilson and Best\(^{68}\) state that there is a common misconception that symptomatic tendon injuries are inflammatory: because of this, these injuries often are mislabeled as “tendonitis.” Acute inflammatory tendinopathies exist, but many patients will have chronic symptoms suggesting a degenerative condition that should be labeled as “tendinosus” or “tendinopathy.” Stasinopoulos and Johnson\(^{69}\) reported a plethora of terms that have been used to describe lateral epicondylitis including tennis elbow, epicondylalgia, tendonitis, tendonosis, and tendinopathy. These terms usually have the prefix extensor or lateral elbow. Lateral elbow tendinopathy seems to be the most appropriate term to use in clinical practice because other terms make reference to inappropriate etiologic, anatomic, and pathophysiologic terms. The correct diagnostic term is important for the right treatment.

Zeisig and colleagues\(^{70}\) and Riley\(^{71}\) also indicate that tennis elbow with tendonosis of extensor carpi radialis brevis is a condition with unknown etiology and pathogenesis, and difficult to treat. Croisier and colleagues\(^{72}\) found that despite the many conservative treatment procedures, prolonged symptoms and relapse are frequently observed. Most treatment options have yet to undergo evaluation for efficacy in well-designed clinical trials, yet there is a generally favorable response to nonoperative or conservative management.\(^{73}\) Wilson and Best\(^{68}\) and Gabel\(^{74}\) indicate that most patients with overuse tendinopathies (about 80%) fully recover within 3 to 6 months. However, 36 years ago Coonrad and Hooper\(^{75}\) provided an overview of the treatment of tennis elbow. What have clinicians learned in the last 3 and a half decades?

**Definitions: Tendonitis and Tendonosis**

As stated earlier in this article, several studies\(^{19,76–78}\) described the histopathological findings showing tennis elbow as a chronic degenerative condition, regeneration, and
microtears of the tendonous tissue called tendonosis. Neurochemicals including glutamate, substance P, and calcitonin gene-related peptides have been identified in patients with chronic tennis elbow and in animal models of tendinopathy. Ashe and colleagues\textsuperscript{79} indicate new research showing that tendons exhibit areas of degeneration and a distinct lack of inflammatory cells. Tendonosis is consequently degeneration of the collagen tissue due to aging, microtrauma, or vascular compromise. Riley\textsuperscript{80} describes the tendon matrix as being maintained by the resident tenocytes, and there is evidence of a continuous process of matrix remodeling, although the rate of turnover varies at different sites. A change in remodeling activity is associated with the onset of tendinopathy and some changes are consistent with repair, but they may also be an adaptive response to changes in mechanical loading. In addition, repeated minor strain is thought to be the major precipitating factor in tendinopathy. Metalloproteinase enzymes have an important role in the tendon matrix, and the role of these enzymes in tendon pathology is unknown; further work is required to identify novel and specific molecular targets for therapy. Riley also states that the neuropeptides and other factors released by stimulated cells or nerve endings in or around the tendon might influence matrix turnover, and could provide novel targets for therapeutic intervention.

Alfredson and Ohberg,\textsuperscript{81} using color Doppler examination, showed structural tendon changes with hypoechoic areas and a local neovascularization, corresponding to the painful area. These investigators demonstrated that treatment with sclerosing injections, targeting the area with neovessels, has the potential to cure the pain in the tendons and also allow patients to go back to full patellar tendon loading activity. Ohberg and Alfredson\textsuperscript{82} examined the occurrence of neovascularization before and after eccentric training in the Achilles tendon. After 12 weeks of painful eccentric calf muscle training there was a more normal tendon structure, and in the majority of the tendons there was no remaining neovascularization.

In addition, Ohberg and colleagues\textsuperscript{83} performed a 12-week eccentric calf muscle training program. Using ultrasonographic follow-up of patients with mid-portion painful chronic Achilles tendonosis treated with eccentric calf muscle training showed a localized decrease in tendon thickness and a normalized tendon structure in most patients. Remaining structural tendon abnormalities seemed to be associated with residual pain in the tendon. Fredberg and Stengard-Pedersen\textsuperscript{77} state that although the prevailing opinion is that no histologic evidence of acute inflammation has been documented, in newer studies using immunohistochemistry and flow cytometry inflammatory cells have been detected. The “tendonitis myth” consequently needs to continue to be pursued and answered. Therefore, the existing data indicate that the initiators of the tendinopathic pathway include many proinflammatory agents. Because of the complex interaction between the classic proinflammatory agents and neuropeptides, it seems impossible and somewhat irrelevant to distinguish between chemical and neurogenic inflammation. Furthermore, glucocorticoids are, at the moment, an effective treatment in tendinopathy with regard to reduction of pain, tendon thickness, and neovascularization. Fredberg and Stengard-Pedersen indicate that an inflammatory process may be related not only to the development of tendinopathy but also chronic tendinopathy.

**Clinical Presentation: Clusters of Signs and Symptoms in Tendonitis versus Tendonosis**

Wilson and Best\textsuperscript{68} describe many of the clinical findings as follows. The natural history is gradually increasing load-related localized pain coinciding with increased activity. The examination should check for the signs of inflammation (swelling, pain, erythema,
and heat) that would indicate a tendonitis response, asymmetry, range of motion testing, palpation for tenderness, and examination maneuvers that simulate tendon loading and reproduce pain. Despite the absence of inflammation, patients with tennis elbow still present with pain. Zeisig and colleagues have suggested the pain involves a neurogenic inflammation mediated via the neuropeptide Substance P. Furthermore, the area with vascularity found in the extensor origin seems to be related to pain. Most likely, the findings correspond with the vasculoneural ingrowth that has been demonstrated in other painful tendonosis conditions. Struijs and colleagues evaluated the predictive value of diagnostic sonography for the effectiveness of conservative treatment of tennis elbow. However, the use of sonography for the detection of abnormalities in this study demonstrated limited value.

There is no consensus regarding the optimum treatment for tendonitis versus tendonosis. Paoloni and colleagues indicated that no treatment has been universally successful. Nirschl and Nirschl and Ashman indicate that the primary goal of nonsurgical treatment is to revitalize the unhealthy tissue that produces pain. Revascularization and collagen repair of the pathologic tissue is the key to a successful rehabilitation program. These investigators state that successful nonsurgical treatment involves rehabilitative resistance exercises and progression of the exercise program. A variety of treatment interventions have been reported in the literature, including hypospray, topical nitric oxide, oxygen free radicals, ice, phonophoresis and ultrasound, low-level laser, extracorporeal shock wave therapy, deep transverse friction massage (DTFM), manipulation and mobilization, acupunture, bracing, orthotics, combined low-level laser and plyometrics, eccentric training programs, eccentric isokinetic program, and a combined exercise program.

**Additional Treatments for Tennis Elbow**

Forty years ago, Hughes and Currey described the use of hypospray as a treatment of tennis elbow. An instrument capable of injecting a fine spray of liquid (25 mg hydrocortisone acetate) through intact skin to a depth comparable with an intramuscular injection was the mode of treatment for lateral elbow tendinopathy (LET). Paoloni and colleagues, in a well-designed study, demonstrated that the application of topical nitric oxide improved early pain with activity, late functional measures, and outcomes of patients with LET. Murrell recently described the effectiveness of randomized, controlled clinical trials (RCTs) evaluating the efficacy on nitric oxide donation via a patch in the management of tendinopathy. Manias and Stasinopoulos used ice as a supplement to an exercise program that has been recommended for the management of LET. Ice was used as a supplement along with eccentric exercises and stretching in a rehabilitation program. There were no significant differences in the magnitudes of reduction between the groups at the end of treatment and at the 3-month follow up. However, because of the confounding variables with multiple treatment interventions, it is difficult to determine the efficacy. Klaiman and colleagues demonstrated that ultrasound results in decreased pain and increased pressure tolerance in selected soft tissue injuries. The addition of phonophoresis with fluorocinonide does not augment the benefits of ultrasound alone.

Bjordal and colleagues performed a systematic review and meta-analysis for low-level laser therapy (LLLT) in LET. Twelve RCTs satisfied the methodological inclusion criteria. LLLT administered with optimal doses of 904 nm and possibly 632 nm wavelengths directly to the lateral elbow tendon insertions seem to offer short-term pain relief and less disability in LET, both alone and in conjunction with an exercise regimen. Stasinopoulos and Johnson used a qualitative analysis of 9 studies that met the
inclusion criteria. Poor results were revealed as to the effectiveness of LLLT for LET because it is a dose-response modality, and the optimal treatment dosage has not been identified.

Rompe and colleagues\textsuperscript{94} performed an RCT and found that eccentric loading showed inferior results to low-energy shock wave therapy as applied in patients with chronic recalcitrant tendinopathy of the insertion of the Achilles tendon. Wang and colleagues\textsuperscript{107} demonstrated that extracorporeal shock wave therapy appeared to be more effective and safer than traditional conservative treatments in the management of patients with chronic patellar tendinopathy.

Rompe and Maffulli\textsuperscript{95} performed a qualitative study-by-study assessment that was thought to be of greater relevance than a pooled meta-analysis of statistically and clinically heterogeneous data of RCTs, which are difficult to interpret. This study included 10 trials that included 948 participants. In a qualitative systematic per-study analysis identifying common and diverging details of 10 RCTs, evidence was found for effectiveness of shock wave treatment for tennis elbow under well-defined, restrictive conditions only.

Brosseau and colleagues\textsuperscript{98} in their Cochrane review, determined that DTFM combined with other physiotherapy modalities did not show consistent benefit over the control of pain, improvement of grip strength, and functional status for patients with extensor carpi radialis tendonitis (ECRT). Low-level laser and plyometrics were more effective using a variety of outcome measures than plyometrics by themselves for treatment of lateral epicondylitis.\textsuperscript{91} Stergioulas and colleagues,\textsuperscript{92} in a Level I RCT study, found that LLLT accelerated clinical recovery from chronic Achilles tendinopathy when added to an eccentric exercise regimen.

\textbf{Eccentric Training Programs}

One specific variable studied with specific regard to treatment of tendon pathology is the use of eccentric exercise. There is limited research regarding the efficacy of eccentric overload training with LET and treatment of other tendon overuse injuries. Kingma and colleagues\textsuperscript{108} performed a systematic review of eccentric overload training in patients with chronic Achilles tendinopathy. Nine clinical trials met the inclusion criteria. The included trials showed an improvement in pain after eccentric overload training. However, because of the methodological shortcomings of the trials, no definite conclusion can be drawn concerning the effects of eccentric overload training. Although the effects of eccentric exercise training in tendinopathy on pain are promising, the magnitude of the effects cannot be determined. Knobloch,\textsuperscript{103} using a laser Doppler system for capillary blood flow, tissue oxygen saturation, and postcapillary venous filling pressure, evaluated the tendon’s microcirculation in response to a 12-week daily painful home-based eccentric training regimen (3 × 15 repetitions per tendon each day). Knobloch found that daily eccentric training for Achilles tendinopathy is a safe and easy measure, with beneficial effects on the microcirculatory tendon levels without any adverse effects in both mid-portion and insertional Achilles tendinopathy. Malliaras and colleagues\textsuperscript{102} performed a MEDLINE database search on eccentric training programs for LET. Their results demonstrated that eccentric training in the management of LET has demonstrated encouraging results, although the literature is limited and eccentric programs are varied.

\textbf{Combined Exercise Programs}

Stasinopoulos and colleagues\textsuperscript{105} described the use and effects of strengthening and stretching exercise programs in the treatment of LET. These investigators recommend slow progressive eccentric exercises being performed with the elbow in extension,
forearm in pronation, and wrist in an extended position. However, they admit the details regarding speed of loading and the details (reps, sets, volume) of the eccentric exercise programs have not been defined. Stasinopoulos and colleagues also recommended static stretching exercises to the lateral muscle tendon unit (MTU) before and after the eccentric exercises for 30 to 45 seconds with a 30-second rest interval between each procedure. However, the details of the optimum parameters for treating LET have yet to be elucidated in a well-designed trial.

There are a few systematic reviews using eccentric exercises in treating patients with lower extremity tendonosis.\textsuperscript{109,110} Wasielewski and Kotsko\textsuperscript{109} reviewed 11 studies in their systematic review, and the methodological score was 5.3 out of 10 based on the PEDro criteria. Based on the best evidence available, it seems that eccentric exercise may reduce pain and improve strength in lower extremity tendinosis, but whether eccentric exercise is more effective than other forms of therapeutic exercise for the resolution of tendonosis symptoms remains questionable. Woodley and colleagues\textsuperscript{110} evaluated 20 relevant studies using the PEDro scale, which included treating lower and upper extremity tendinopathies. These investigators reached a similar conclusion, which demonstrates the dearth of high-quality research in support of the clinical effectiveness of eccentric exercise over other treatments in the management of tendinopathies.

**Rotator Cuff and Scapular Stabilization**

In addition to the use of therapeutic modalities and eccentric exercise to directly address the injured tendon at the elbow, the use of proximal stabilization and exercise techniques are also warranted during the treatment of the athlete with overuse elbow injury. Several key scapular strengthening exercises that target strengthening of the lower trapezius and serratus anterior force couple are recommended.\textsuperscript{111} Scapular stabilization exercises are emphasized, and include external rotation with retraction (Fig. 6), an exercise shown to recruit the lower trapezius at a rate 3.3 times more than the upper trapezius and use the important position of scapular retraction.\textsuperscript{112} Multiple seated rowing variations are recommended. These variants include the

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**Fig. 6.** External rotation with scapular retraction with elastic resistance.
lawn mower exercise (Fig. 7) and low row variations, which have been studied with EMG quantification by Kibler and colleagues.\textsuperscript{113}

Progression to closed chain exercise using the “plus” position, which is characterized by maximal scapular protraction, has been recommended by Moesley and colleagues\textsuperscript{114} and Decker and colleagues\textsuperscript{115} for its inherent maximal serratus anterior

![Fig. 7. (A, B), Lawn mower exercise for scapular stabilization using elastic resistance.](image)

![Fig. 8. Closed chain step-ups for scapular stabilization.](image)
1. SIDELYING EXTERNAL ROTATION:
Lie on uninvolved side, with involved arm at side, with a small pillow between arm and body. Keeping elbow of involved arm bent and fixed to side, raise arm into external rotation. Slowly lower to starting position and repeat.

2. SHOULDER EXTENSION:
Lie on table on stomach, with involved arm hanging straight to the floor. With thumb pointed outward, raise arm straight back into extension toward your hip. Slowly lower arm and repeat.

3. PRONE HORIZONTAL ABDUCTION:
Lie on table on stomach, with involved arm hanging straight to the floor. With thumb pointed outward, raise arm out to the side, parallel to the floor. Slowly lower arm, and repeat.

4. 90/90 EXTERNAL ROTATION:
Lie on table on stomach, with shoulder abducted to 90 degrees and arm supported on table, with elbow bent at 90 degrees. Keeping the shoulder and elbow fixed, rotate arm into external rotation, slowly lower to start position, and repeat.

Fig. 9. Rotator cuff exercise movement patterns based on EMG research emphasizing posterior rotator cuff activation and positions with less than 90° of glenohumeral joint elevation.

recruitment. Closed-chain step-ups (Fig. 8), and quadruped position rhythmic stabilization and variations of the pointer position (unilateral arm and ipsilateral leg extension weight bearing) are all used in endurance-oriented formats (timed sets of 30 seconds or more) to enhance scapular stabilization. Uhl and colleagues\textsuperscript{116} have demonstrated the effects of increasing weight bearing and successive decreases in the number of weight-bearing limbs on muscle activation of the rotator cuff and scapular musculature, and provide guidance for closed-chain exercise progression in the upper extremity.

Strengthening the posterior rotator cuff to provide strength, fatigue resistance, and optimal muscle balance are of paramount importance when working with individuals in this population. Fig. 9 shows the recommended exercises used by the authors of this article for rotator cuff strengthening. These exercises are based on EMG research showing high levels of posterior rotator cuff activation.\textsuperscript{117–120} Use of the prone horizontal abduction exercise is emphasized, as research has shown this position to create high levels of supraspinatus muscular activation,\textsuperscript{117,118} making it an alternative
to the widely used empty-can exercise that often can cause impingement due to the combined inherent movements of internal rotation and elevation. Three sets of 15 to 20 repetitions are recommended to create a fatigue response and improve local muscular endurance.\textsuperscript{121} For application to the patient with elbow dysfunction, these exercises can be performed using a cuff weight attached proximal to the elbow if distal weight attachment provokes pain or stress to the healing elbow structures. Moncreif and colleagues\textsuperscript{122} have demonstrated the efficacy of these exercises in a 4-week training paradigm, and measured 8\% to 10\% increases in isokinetically measured internal and external rotation strength in healthy subjects. These isotonic exercises are coupled with an external rotation exercise with elastic resistance, to provide resistance to the posterior rotator cuff in both a neutral and 90° abducted position in the scapular plane.

Recent research has provided guidance regarding the use of resistive exercise in shoulder rehabilitation. Bitter and colleagues\textsuperscript{123} measured EMG activity of the infraspinatus and middle and posterior deltoid during external rotation exercise in healthy subjects. Monitoring of muscular activity occurred during external rotation exercise at 10\%, 40\%, and 70\% activation levels (percentage of maximal). Their important study found increased relative infraspinatus activity when the resistive exercise level was at 40\% of maximal effort, indicating more focused activity from the infraspinatus and less compensatory activation of the deltoid. This study confirms that the use of lower intensity strengthening exercises optimizes the activation from the rotator cuff and deemphasizes the input from the deltoid and other prime movers that often occurs with higher intensity resistive loading.

Carter and colleagues\textsuperscript{124} studied the effects of an 8-week training program of plyometric upper extremity exercise and external rotation strengthening with elastic resistance. These investigators found increased eccentric external rotation strength, concentric internal rotation strength, and improved throwing velocity in collegiate baseball players, showing the positive effects of plyometric and elastic resistance training in overhead athletes. \textbf{Fig. 10} shows a prone 90/90 plyometric that can be used with the athlete maintaining a retracted scapular position with the shoulder in 90° of abduction and 90° of external rotation. The plyo ball is rapidly dropped and

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig10.png}
\caption{Prone 90/90 external rotation plyometric.}
\end{figure}
caught over a 2- to 3-inch (3 to 6 cm) movement distance for sets of 30 to as much as 40 seconds to address local muscular endurance. Fig. 11 shows a reverse catch plyometric exercise that is performed again with the glenohumeral joint in the 90/90 position. The ball is tossed from behind the patient to load eccentrically the posterior rotator cuff (external rotators) with a rapid concentric external rotation movement performed as the patient throws the ball back, keeping the abducted position of the shoulder with 90° of elbow flexion. These one-arm plyometric exercises can be preceded by two-arm catches over the shoulder to determine readiness for the one-arm loading. Small 1-pound (0.5 kg) medicine balls or soft weights (Theraband; Hygenic Corporation, Akron, OH) are used initially with progression to 1 to 1.5 kg as the patient progresses in both skill and strength development.

Distal Upper Extremity Exercises for the Adolescent Overhead Athlete

Exercises to improve strength and promote muscular endurance of the forearm and wrist include both traditional curls for the flexors and extensors with either light isotonic dumbbells or elastic tubing or bands, as well as forearm pronation/supination and radioulnar deviation with a counterbalanced weight. Although truly simplistic, these exercises help to provide additional muscular support to the distal extremity, and provide protection and countering to the large forces in this region encountered with both throwing and overhead serving motions.

Due to the anatomic orientation of the flexor carpi ulnaris and flexor digitorum superficialis overlaying the ulnar collateral ligament, isotonic and stabilization activities for these muscles may assist in stabilizing the medial elbow in the overhead throwing athlete. These isotonic exercises with light weights or elastic tubing or bands form the cornerstone of the base program for distal strengthening.
Integration of more advanced, ballistic type exercises can be recommended for these athletes. Rapid ball dribbling in sets of 30 seconds with a basketball or small physio ball both off the ground and in an elevated position off the wall (Fig. 12) are recommended. In addition, specific plyometric drills for the forearm musculature include wrist flexion flips (Fig. 13) and wrist flexion snaps (Fig. 14). A plyometric exercise used
in end-stage rehabilitation to provide a valgus overload stress is the internal rotation
plyometric in 0° abduction (Fig. 15) This exercise can prepare the athlete for throwing
activity using a controlled overload stress in the clinical environment. All the plyometric
drills constitute an important component of an end-stage rehabilitation program as
well as a sport-specific conditioning program for throwing athletes.

Fig. 14. Plyometric wrist snaps.

Fig. 15. Shoulder internal rotation (neutral) plyometric.
Return to Sport/Interval Return Programs

Of the phases employed in the rehabilitation process for elbow injury, the return to activity phase is the one that is most frequently ignored or cut short, resulting in serious consequences for reinjury. Objective criteria for entry into this stage are: tolerance of the previously stated resistive exercise series, objectively documented strength equal to the contralateral extremity with either manual assessment (manual muscle testing) or preferably isokinetic testing and isometric strength, distal grip strength measured with a dynamometer, and a functional range of motion. Of note, often in the elite athlete with chronic musculoskeletal adaptations full elbow range of motion is not always attainable, secondary to the osseous and capsular adaptations discussed earlier in this article.

Characteristics of interval sport return programs include alternate day performance, as well as gradual progressions of intensity and repetitions of sport activities. For the interval tennis program, for example, low-compression tennis balls such as the Pro-Penn Star Ball (Penn Racquet Sports, Phoenix, AZ) or foam balls used during the teaching process of tennis to children can be used. These balls are highly recommended for use during the initial phase of the return to tennis program, and result in a decrease in impact stress and increased patient tolerance to the activity. In addition, 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 risk of reinjury.

An interval tennis program has been published,64,127 and the reader is referred to these publications for additional discussion of this important process. In addition, similar concepts are employed in the interval throwing program that has been published previously.128 Similar to the interval tennis program, having the patient’s throwing mechanics evaluated using video and by a qualified coach or biomechanist are very important parts of the return to activity phase of the rehabilitation process.

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. 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 upper extremity injury histories.5,6,17 Grip size is also very important, with research showing changes in muscular activity with alteration of handle or grip size.129 Measurement of proper grip size has been described by Nirschl16 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. Groppel and Nirschl130 have also recommended the use of a counterforce brace to decrease stress on the insertion of the flexor and extensor tendons during work or sport activity.

SUMMARY

Treatment of the athlete with an overuse injury requires a thorough evaluation and treatment of the entire upper extremity kinetic chain. Although there are many options
available to address elbow pain in the early stages of the rehabilitation process, current evidence is limited as to the identification of a superior modality or series of modalities to attain this important initial goal. The use of an exercise-based approach for the entire upper extremity kinetic chain is recommended, along with a return to a sport program based on objective testing to ensure patient readiness to minimize the effects of reinjury.

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