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Medial Collateral Ligament Injuries in the Overhead Athletes

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28.1 Introduction

Medial ulnar collateral ligament (MUCL) injuries can cause pain and elbow instability in the overhead throwing athlete. One of the earliest reports of an injury to the MUCL was in javelin throwers [1]. Periarticular loose bodies identified on radiographs were initially recognized in professional baseball pitchers [2]. Pitchers were noted to have valgus deformity of the throwing arm, and these loose bodies were discovered to be a result of compression of the radiocapitellar joint surfaces secondary to "medial elbow strain" [3]. Case reports of MUCL injuries were later described in baseball pitchers [4]. Some of the initial reports were of surgical repair of the torn ulnar collateral ligament in an acute setting [5]. Reconstruction of the MUCL became popularized with one of its first success stories, professional baseball pitcher Tommy John by Dr. Frank Jobe. Tommy John surgery, or MUCL reconstruction, was first described using the Jobe technique in 1986 [6]. A modification of this original procedure is still widely used today. As our understanding of the anatomy and biomechanics of the MUCL has evolved, additional techniques have been described to minimize morbidity associated with the procedure and improve outcomes.

28.2 Pathoanatomy, Biomechanics, and Preferred Classification

28.2.1 Pathoanatomy

The medial ulnar collateral ligament complex (MUCL) is composed of three structures: anterior bundle, posterior bundle, and transverse segment [7, 8]. The posterior bundle is a thickening of the elbow joint capsule [7]. The transverse ligament does not cross the ulnohumeral joint, is difficult to identify in all cadaver specimens, and plays no role in the stability of the elbow joint [8]. The origin of the MUCL is located on the posterior and inferior aspect of the medial epicondyle [7, 8]. Although originally thought to have a common origin, separate origins have been described for the different bundles on the medial epicondyle. The anterior bundle is divided into anterior and posterior fibers [7, 8]. The anterior fibers insert on to the sublime tubercle of the ulna. There is variability in the anatomy of the origin, insertion, and width of the anterior bundle

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of the ulnar collateral ligament [9]. The mean length of the anterior portion of MUCL is about 27 mm and the mean width is 4–5 mm [8]. Part of this variability can be explained by an increase in width of the ligament toward its insertion. It has a broad insertion on the sublime tubercle from within several millimeters of the joint line and it tapers distally [9]. The flexor carpi ulnaris is the predominant muscle of the flexor-pronator muscle group that originates overlying the MUCL and is anatomically situated as an important dynamic restraint to valgus elbow instability [10]. The flexor digitorum superficialis muscle is the only other significant contributor. The role of these muscles as dynamic stabilizers may have implications in the rehabilitation of the overhead throwing athlete.

28.2.2 Biomechanics

The pathology generated in the thrower's elbow is a result of the forces generated during throwing. Tensile forces are generated medially (which leads to injuries to the MUCL, ulnar nerve, flexor-pronator musculature), and compressive forces are generated laterally (which leads to radiocapitellar arthrosis and loose bodies). Shear forces are generated posteriorly during late acceleration and follow through phases of pitching (which leads to posteromedial impingement and osteophytes). Kinematic studies of baseball pitchers have shown that the elbow experiences valgus forces that are greatest during the late cocking and early acceleration phase of throwing [11]. When the shoulder reaches maximum external rotation, 64 N-m of elbow valgus torque is generated [11]. Biomechanical tests of the strength of the anterior bundle of the MUCL show average failure load of 260 N [12]. Every pitch approaches the maximal load to failure of the MUCL complex [11]. This finding reinforces the importance of the dynamic stabilizers of the elbow. The palmaris longus tendon, the most common source of autograft for ligament reconstruction, has been shown to have a similar failure load of 357 N [12].

The MUCL is the most important ligamentous static restraint to valgus elbow instability [13]. Deficiency of the anterior bundle of the MUCL alone will create valgus elbow instability [14, 15]. In contrast to the isometric position of the lateral collateral ligament, the MUCL origin is posterior to the axis of flexion-extension of the ulnohumeral joint. [8] Flexion and extension of the elbow joint creates reciprocal tension in the anterior and posterior fibers of the anterior bundle of the MUCL due to a cam effect as the elbow is brought into flexion [14]. The distance between the origin and insertion of the anterior bundle of the MUCL increases slightly from extension to 60° of flexion and then remains relatively constant. An isometric group of fibers within the MUCL does not exist, but there are fibers within the central portion that approximate true isometry and serve as the basis for single-strand reconstruction techniques [16]. The posterior bundle of the MUCL is a secondary restraint to valgus instability. Isolated sectioning of the posterior bundle does not lead to valgus elbow instability unless the anterior bundle of the MUCL is also deficient [14]. As the anterior bundle of the MUCL is the primary ligamentous restraint to elbow valgus instability, reconstructive efforts have focused on restoring the function of this ligament.

The flexor-pronator muscle groups act as an important dynamic restraint to valgus elbow instability. There is increased EMG activity of the flexor-pronator muscle group during the late cocking and early acceleration phase of throwing [17, 18]. The FCU is considered to be a primary dynamic stabilizer and the FDS a secondary stabilizer because contraction of the FCU alone allowed correction of the valgus instability in cadaveric specimens with MUCL tears [19]. Muscles that cross joints increase the joint reaction force during contraction. This effect can increase the constraint from the bony geometry of the ulnohumeral articulation which has been described as a "sloppy hinge joint."

28.2.3 Preferred Classification

Injuries to the MUCL are commonly classified as acute or chronic. Chronic injuries are repetitive, overuse injuries without a history of a traumatic event. Acute injuries are injuries where the athlete recalls a single throw or traumatic event where a valgus load was applied to the arm. Oftentimes, injuries to the MUCL are the result of an acute episode or traumatic event in the setting of underlying microtrauma as a result of repetitive overhead throwing.

28.3 Clinical Presentation and Essential Physical Examination Maneuvers

A detailed history is important in the evaluation of the throwing athlete. They may recall a particular throw where they experienced a "pop" in the elbow. Oftentimes, there was not a specific injury, but the patient will complain of a decrease in throwing velocity or accuracy. It is important to elicit which phase of the throwing cycle the athlete experiences symptoms. The athlete with an injury to the MUCL commonly describes medial elbow discomfort prior to ball release. Pain after ball release is more often due to valgus extension overload syndrome. Numbness and tingling should alert the examiner to concomitant ulnar neuritis. Arm dominance, player position, level of play, and duration of nonoperative treatment are important elements of the history that may guide operative decision making. For example, symptoms in the nondominant arm of an outfielder who plays in a recreational league may be successfully managed with nonoperative treatment, whereas symptoms in the dominant arm of a major league baseball pitcher may be a career-ending injury without surgical reconstruction.

A deficiency in the kinetic chain of throwing can occur anywhere from the core to the upper extremity, so physical examination in the overhead athlete begins with an evaluation of core strengthening. Evaluate for "cork screwing" or inability to maintain balance while squatting on one leg. It is important to examine the ipsilateral shoulder for rotation deficits. There is some evidence to suggest that glenohumeral internal rotation deficit is associated with valgus elbow injuries in baseball players [20]. On examination of the elbow, inspect the medial skin for signs of acute injury such as overlying ecchymosis and edema. Range of motion deficits, particularly flexion contractures, are common in baseball pitchers and usually do not create functional impairment. A variety of tests have been described to assess for valgus elbow instability. We prefer the moving valgus stress test, described by O'Driscoll [21]. With the patient sitting upright and the shoulder at maximal external rotation, a valgus stress is applied to the elbow as it is extended to 30° of flexion (Fig. 28.1). The test is considered positive if the pain is reproduced or the point of maximum pain is from 120° to 70° of flexion. In a group of 21 patients, the test had a sensitivity (100 %) and a specificity (75 %) when compared to arthroscopic diagnosis [21]. The examiner should evaluate for ulnar neuritis in all patients with suspected MUCL sufficiency because of the high degree of association. Assess for a Tinel's sign over the cubital tunnel or reproduction of numbness and tingling in the ulnar one and one half digits with prolonged flexion of the elbow. Spontaneous subluxation of the ulnar nerve with elbow flexion can be an asymptomatic

Fig. 28.1 Moving valgus stress test

finding. Nerve conduction studies can be obtained but may be falsely negative because compression of the nerve is often a dynamic phenomenon experienced only during the throwing motion. We have found the history and physical examination findings to be more accurate in guiding treatment. In athletes with acute traumatic valgus injuries, palpate for muscle ruptures along the origin of the flexor-pronator mass muscle belly. Remember that medial epicondylitis is a common source of medial elbow pain in the overhead throwing athlete.

28.4 Essential Radiology

The workup of medial elbow pain in the overhead athlete begins with an anteroposterior and lateral radiograph of the elbow. Radiographs should be examined for osteophytes associated with posteromedial impingement, radiocapitellar arthritis, and intra-articular loose bodies. An oblique view has been described for optimal visualization of posteromedial olecranon spurs, but in our experience, a good lateral radiograph is sufficient. Stress radiographs have fallen out of favor and are not routinely obtained. Magnetic resonance imaging (MRI) of the elbow is usually performed with contrast to evaluate for an injury to the MUCL and intra-articular pathology. A T-sign has been described to diagnose tears of the MUCL as fluid extravasates between the MUCL and its origin on the humerus where it has peeled off [22] (Fig. 28.2). Whereas nonenhanced MRI has a high specificity (100 %) but a low sensitivity (57 %) [22], saline-enhanced MRI arthrography increases the sensitivity to 92 % [23]. Stress ultrasound is emerging as an alternative technique to MRI in the evaluation of MUCL injuries [24].

28.5 Disease-Specific Clinical and Arthroscopic Pathology

MUCL injuries are often partial-thickness tears associated with chronic overuse injuries and microtrauma. Full-thickness tears may be seen in patients who sustain contact-associated valgus loading of the elbow. Ulnar neuritis may develop in association with medial elbow instability as traction is applied to the ulnar nerve from valgus instability.

Fig. 28.2 T-sign

Several authors have described arthroscopic techniques to assist with diagnosis of an MUCL injury [25, 26]. Only the most anterior 25 % of the anterior bundle can be visualized arthroscopically [26]. Because the ligament cannot be visualized in its entirety arthroscopically, a cadaveric study looked at the degree to which the medial compartment gaps open with stress arthroscopically. Field and Altchek found that at 70° of elbow flexion, sectioning of the anterior bundle of the MUCL leads to 1–2 mm of opening, whereas sectioning of the entire MUCL leads to 4–10 mm of opening [26]. The advantage of arthroscopy is that it can be used to address intra-articular pathology that otherwise might not be

Fig. 28.3 Setup for elbow arthroscopy

Fig. 28.4 Chondral full-thickness lesion

Fig. 28.5 Microfracture

accessible from an open medial exposure of the ulnohumeral joint. Chondral lesions typically present on the radiocapitellar joint surface due to lateral compressive loading. Microfracture and chondroplasty are arthroscopic techniques that can be used to address chondral lesions. Posteromedial olecranon spurs can be removed arthroscopically or from an open medial approach (Figs. 28.3, 28.4, 28.5, and 28.6).

28.6 Treatment Options

Surgical treatment options for MUCL insufficiency generally involve reconstruction of the ligament. Repair of the MUCL is mainly of historical interest only. There is some evidence to suggest that repair of the MUCL may be beneficial in the younger, nonprofessional athlete. Savoie et al. performed a repair using mostly

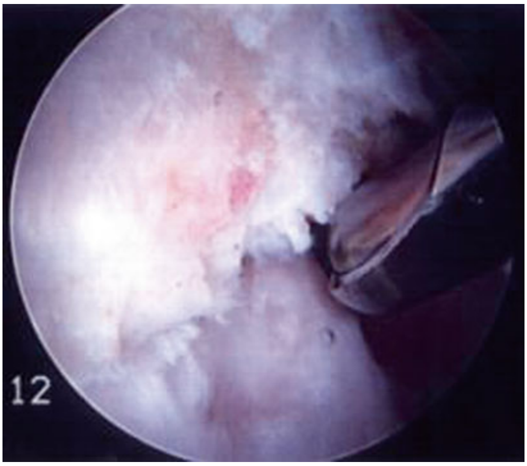

Fig. 28.6 Removal of posteromedial osteophyte with burr

suture anchors in 60 patients (average age 17) and reported good to excellent outcomes in 93 % with return to play at 6 months. There were 4 failures and the average follow-up was 5 years. Other studies have shown higher failure rates with MUCL repair compared to reconstruction [27].

The Jobe technique is the first procedure to describe reconstruction of the MUCL. The procedure involves elevation of the flexor-pronator mass off the medial epicondyle, creation of tunnels in the sublime tubercle and medial epicondyle, and passage of a free graft (usually palmaris longus autograft) in a figure-of-eight fashion. Ten of 16 (68 %) patients returned to previous level of play in his original series [6].

A muscle-splitting approach was described by Smith and Altchek to minimize the morbidity associated with surgical dissection of the flexor-pronator musculature [28]. Twenty-two patients underwent repair or reconstruction using a muscle-splitting approach without neuropathy. It involves tunnel placement and graft passage through the raphe of the flexor carpi ulnaris in the safe interval between the median and ulnar nerves.

Andrews described a modified Jobe technique that involved routine transposition of the ulnar nerve under a fascial sling. Cain et al. reported Andrews' experience using this technique in 1,281 athletes with 79 % follow-up at 2 years. Eighty-three percent of reconstructions returned to the same level. Sixty-three percent of repairs returned to the same level. Athletes returned to play on average at 11.6 months and initiated a throwing program at 4.4 months.

Altchek coined the docking technique, which involved "docking" of the graft into a single tunnel on the ulna and the humerus with the sutures tied over smaller tunnels to create a bone bridge. This reduces the number of large drill holes in the medial epicondyle from three to one. Dodson et al. described Altchek's experience using the docking technique in 100 consecutive patients. A subcutaneous ulnar nerve transposition was performed selectively in a few cases. Ninety out of 100 competed at the same level or higher for more than 12 months. There were 2 poor results. There were 3 postoperative complications (2 late ulnar nerve transpositions and 1 arthroscopic lysis of adhesions).

Another technique is called the DANE TJ procedure named to give credit for those who envisioned it (David Altchek, Neal ElAttrache, Tommy John). It involves a hybrid form of fixation with a docking technique proximally and interference screw fixation distally. Dines et al. described the results of the DANE TJ technique in 22 athletes. Nineteen of 22 achieved excellent outcomes, 4 of 22 (17 %) had complications, and 3 required second surgery (2 with arthroscopic lysis of adhesions, 1 with posteromedial osteophyte debridement, all achieved excellent outcomes). Advantages of this technique include its application for revision procedures and sublime tubercle insufficiency where tunnel fracture and/or placement may be potential issues. Proponents of this technique argue that optimal graft tensioning is easier. Ahmad et al. described a technique that involved interference screw fixation proximally and distally in an attempt to more closely recreate ligament isometry [29].

In the initial reports of reconstruction of the MUCL, ulnar nerve transposition was routinely concomitantly performed. However, high incidences of postoperative ulnar neuropraxia led to more selective use of ulnar nerve transposition. When Conway et al. reported Jobe's 13-year experience, there was transfer of the ulnar nerve in 56 patients that led to 68 % return to previous level of performance, 24 % ulnar nerve-related symptoms(both transient and non-transient), and a 13 % reoperation rate for ulnar nerve-related symptoms [30]. In a later report of 83 patients without nerve transfer using the Jobe technique and the muscle-splitting approach, 82 % returned to their previous level of performance, 5 % had transient nerve-related symptoms, and there were no reoperations [31]. Today most surgeons recommend nerve transposition on a select basis.

Biomechanical studies using a cyclic loading protocol compared the docking technique, figure-of-eight technique, interference screw fixation, and suspensory fixation (Endobutton) [32]. All failed at lower loads than the native MUCL. The docking technique and suspensory fixation showed the highest peak loads to failure. Clinically, excellent outcomes and low failure rates have been obtained with many of these techniques, and none has demonstrated superiority.

28.7 Authors' Preferred Treatment

We prefer the docking technique as described by Altchek. The first stage of the procedure involves arthroscopy of the elbow, if indicated, to address intra-articular pathology such as chondral injury or posteromedial osteophytes. The graft is then harvested (Fig. 28.7). We use a palmaris longus autograft if available from the ipsilateral or contralateral extremity. If not available, we use a gracilis autograft from the contralateral (plant leg when throwing) lower extremity. The palmaris longus tendon is harvested from a 1 cm incision placed over the volar wrist crease. The visible portion of the tendon is tagged with a no. 1 Ethibond suture in a Krackow fashion. The proximal portion of the tendon is harvested with a tendon stripper. The incision is closed and the tendon is placed in moistened lap sponge.

The arm is exsanguinated and a tourniquet is elevated. We make an 8–10 cm incision over the medial elbow from the distal third of the intermuscular septum to 2 cm beyond the sublime tubercle. Branches of the medial antebrachial cutaneous nerve are identified with vessel loops and carefully retracted. A muscle-splitting approach is developed through the posterior third of the common flexor-pronator mass musculature and within the anterior fibers of the flexor carpi ulnaris (Fig. 28.8). An incision is made longitudinally along the anterior bundle of the MUCL.

Fig. 28.7 Harvest of palmaris longus tendon

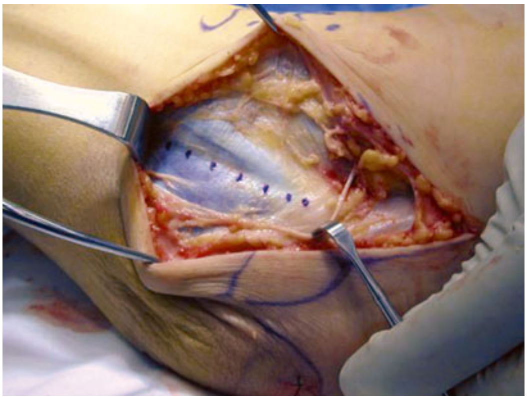

Fig. 28.8 Muscle-splitting approach

The location of the ulnar tunnel is identified after exposing 4–5 mm posterior to the sublime tubercle in a subperiosteal fashion. We use a 3 mm burr for creation of anterior and posterior tunnels on the sublime tubercle with a 2 cm bone bridge between tunnels. The tunnels are connected with a small, curved curette. A suture passer is passed through the tunnels to shuttle looped sutures through them and aid with graft passage. Sutures are passed and tied over the bony bridge after the graft is docked in the ulnar tunnel. The humeral epicondyle is carefully

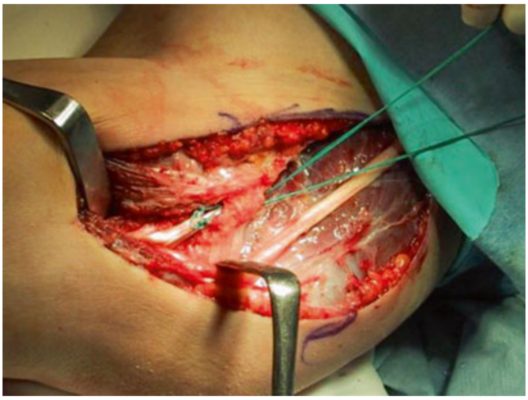

Fig. 28.9 Passage of sutures through bone tunnels on the medial epicondyle after docking of graft

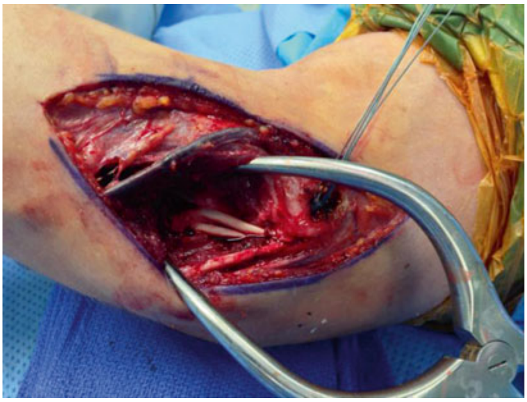

Fig. 28.10 Appearance of graft after final tensioning

exposed without dissection of the ulnar nerve unless transposition is planned. The origin of the humeral tunnel is identified and a longitudinal tunnel is created using a 4 mm burr. Two smaller anterior tunnels are created with the use of a 1.5 mm burr anterior to the intramuscular septum approximately 5–10 mm apart. The incision in the native MUCL is repaired with 2-0 absorbable suture. Sutures are shuttled through the tunnels using a suture passer and shuttling technique as previously described.

The forearm is supinated and a slight varus stress is applied to the elbow. The limb of the graft with sutures is passed through the ulnar tunnel from anterior to posterior and “docked” into the humeral tunnel with sutures exiting one of the smaller 1.5 mm tunnels. The graft is tensioned in flexion and extension to determine what length is optimal before securing the second limb of the graft in the humeral tunnel. The other limb is marked and a no. 1 Ethibond suture is placed in a Krackow fashion. The excess graft is removed and the graft is docked into the humeral tunnel with the sutures exiting the other 1.5 mm tunnel (Fig. 28.9). The elbow is taking through full range of motion prior to final graft tensioning, and once satisfied, the sutures are tied over the bone bridge on the medial epicondyle (Fig. 28.10). The tourniquet is deflated and hemostasis is obtained. The flexor-pronator fascia is reapproximated and the wound is closed in layers. We perform an ulnar nerve transposition only if indicated based upon preoperative examination. The elbow is placed in a well-padded, plaster splint at 45° of flexion.

28.8 Rehabilitation

At the first postoperative visit, the sutures are removed and the patient is placed in a hinged elbow brace. For the first 3 weeks, we allow motion from 30° to 90°. From the third to the fifth week, motion is advanced to 15° of extension and 115° of flexion. We remove the hinged elbow brace after 6 weeks. Patients are then started in physical therapy. Physical therapy initially focuses on passive elbow, shoulder, forearm, wrist, and hand range of motion. At 12 weeks, we allow a more aggressive program that includes shoulder and scapula strengthening. Usually a formal tossing program is begun at 4 months. If patients can throw pain free to 180 ft at 9 months, we allow them to begin pitching from a mound. Patients are generally now allowed to return to competitive pitching about 1 year after surgery.

Nonoperative treatment can be successful in returning some athletes to competition. A supervised rehabilitation program consisting of rest for 2–3 months followed by progressive strengthening and throwing with gradual return to play allowed 41 % of athletes to return to play at their previous level of performance at an average of 24.5 weeks [33].

28.9 Advantages/Pitfalls/Complications

The most common complication described with reconstructive MUCL surgery is injury to the medial antebrachial cutaneous injury. Other more serious complications include retear, ulnar neuropathy, fracture, arthrofibrosis, graft site morbidity, valgus extension overload, infection, saphenous neuropathy (gracilis autograft), and RSD [34]. Revision surgery for ligament reconstruction is not as successful and the overall return to play after a failure or complication is 84 % [34].

We present some pearls that may decrease the risk of complication. Perform meticulous superficial dissection with bipolar electrocautery and vessel loops to minimize iatrogenic injury to branches of the medial antebrachial cutaneous nerve. Maintain at least 10 mm between bone tunnels to minimize iatrogenic fracture. Consider interference screw fixation as a bailout for tunnel fracture. Protect the ulnar nerve carefully at all times, especially during tunnel placement to minimize risk of ulnar nerve injury. Avoid violation of the posterior cortex of the medial epicondyle during creation of the humeral tunnel. Carefully protect the ulnar nerve during subperiosteal exposure of the ulnar tunnel on the sublime tubercle. Plan tunnel placement based upon anatomic landmarks to minimize the risk of tunnel anisometry. Avoid aggressive posteromedial resection and limit resection to only pathologic structures to minimize risk of valgus instability and stress on graft.

28.10 Experience in Treatment of Athletes

Professional and college-level athletes generally have good to excellent outcomes after MUCL reconstruction. Several studies have demonstrated that elite-level athletes can return to sport at a rate of 82–92 % after MUCL reconstruction [31, 35]. Athletes without prior surgery undergoing a primary procedure have been shown to have a higher rate of return to play [31]. A high rate of failure (26 %) has been documented in high school baseball players after MUCL reconstruction [36]. Year-round baseball was the number one risk factor for MUCL tears in this group. Professional quarterbacks with MUCL injuries can be successfully managed with nonoperative treatment [37]. Throwing a football may place different stresses on the elbow compared to throwing a baseball. Carefully consider the player's sport and position when managing athletes with these injuries.

References

1. Waris W. Elbow injuries of javelin-throwers. Acta Chir Scand. 1946;93(6):563–75.
2. Bennett GE. Shoulder and elbow lesions distinctive of baseball players. Ann Surg. 1947;126(1):107–10.
3. King JW, Brelsford HJ, Tullos HS. Analysis of the pitching arm of the professional baseball pitcher. Clin Orthop Relat Res. 1969;67:116–23.
4. Tullos HS, Erwin WD, Woods GW, Wukasch DC, Cooley DA, King JW. Unusual lesions of the pitching arm. Clin Orthop Relat Res. 1972;88:169–82.
5. Norwood LA, Shook JA, Andrews JR. Acute medial elbow ruptures. Am J Sports Med. 1981;9(1):16–9.
6. Jobe FW, Stark H, Lombardo SJ. Reconstruction of the ulnar collateral ligament in athletes. J Bone Joint Surg Am. 1986;68(8):1158–63.
7. Fuss FK. The ulnar collateral ligament of the human elbow joint. Anatomy, function and biomechanics. J Anat. 1991;175:203–12.
8. Morrey BF, An KN. Functional anatomy of the ligaments of the elbow. Clin Orthop Relat Res. 1985; 201:84–90.
9. Dugas JR, Ostrander RV, Cain EL, Kingsley D, Andrews JR. Anatomy of the anterior bundle of the ulnar collateral ligament. J Shoulder Elbow Surg. 2007;16(5):657–60.
10. 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):245–50.
11. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. Am J Sports Med. 1995; 23(2):233–9.
12. Regan WD, Korinek SL, Morrey BF, An KN. Biomechanical study of ligaments around the elbow joint. Clin Orthop Relat Res. 1991;271:170–9.
13. Morrey BF, Tanaka S, An KN. Valgus stability of the elbow. A definition of primary and secondary constraints. Clin Orthop Relat Res. 1991;265:187–95.
14. Callaway GH, Field LD, Deng XH, et al. Biomechanical evaluation of the medial collateral

ligament of the elbow. J Bone Joint Surg Am. 1997;79(8):1223–31.

15. Floris S, Olsen BS, Dalstra M, Sojbjerg JO, Sneppen O. The medial collateral ligament of the elbow joint: anatomy and kinematics. J Shoulder Elbow Surg. 1998;7(4):345–51.
16. Armstrong AD, Ferreira LM, Dunning CE, Johnson JA, King GJ. The medial collateral ligament of the elbow is not isometric: an in vitro biomechanical study. Am J Sports Med. 2004;32(1):85–90.
17. Glousman RE, Barron J, Jobe FW, Perry J, Pink M. An electromyographic analysis of the elbow in normal and injured pitchers with medial collateral ligament insufficiency. Am J Sports Med. 1992;20(3):311–7.
18. Hamilton CD, Glousman RE, Jobe FW, Brault J, Pink M, Perry J. Dynamic stability of the elbow: electromyographic analysis of the flexor pronator group and the extensor group in pitchers with valgus instability. J Shoulder Elbow Surg. 1996;5(5):347–54.
19. Park MC, Ahmad CS. Dynamic contributions of the flexor-pronator mass to elbow valgus stability. J Bone Joint Surg Am. 2004;86-A(10):2268–74.
20. Dines JS, Frank JB, Akerman M, Yocum LA. Glenohumeral internal rotation deficits in baseball players with ulnar collateral ligament insufficiency. Am J Sports Med. 2009;37(3):566–70.
21. O'Driscoll SW, Lawton RL, Smith AM. The "moving valgus stress test" for medial collateral ligament tears of the elbow. Am J Sports Med. 2005;33(2):231–9.
22. Timmerman LA, Schwartz ML, Andrews JR. Preoperative evaluation of the ulnar collateral ligament by magnetic resonance imaging and computed tomography arthrography. Evaluation in 25 baseball players with surgical confirmation. Am J Sports Med. 1994;22(1):26–31; discussion 32.
23. Schwartz ML, al-Zahrani S, Morwessel RM, Andrews JR. Ulnar collateral ligament injury in the throwing athlete: evaluation with saline-enhanced MR arthrography. Radiology. 1995;197(1):297–9.
24. Ciccotti MG, Atanda Jr A, Nazarian LN, Dodson CC, Holmes L, Cohen SB. Stress sonography of the ulnar collateral ligament of the elbow in professional baseball pitchers: a 10-year study. Am J Sports Med. 2014;42:544–51.
25. Timmerman LA, Andrews JR. Histology and arthroscopic anatomy of the ulnar collateral ligament of the elbow. Am J Sports Med. 1994;22(5):667–73.
26. Field LD, Callaway GH, O'Brien SJ, Altchek DW. Arthroscopic assessment of the medial collateral ligament complex of the elbow. Am J Sports Med. 1995;23(4):396–400.
27. Cain Jr EL, Andrews JR, Dugas JR, et al. Outcome of ulnar collateral ligament reconstruction of the elbow in 1281 athletes: results in 743 athletes with minimum 2-year follow-up. Am J Sports Med. 2010;38(12): 2426–34.
28. Smith GR, Altchek DW, Pagnani MJ, Keeley JR. A muscle-splitting approach to the ulnar collateral ligament of the elbow. Neuroanatomy and operative technique. Am J Sports Med. 1996;24(5):575–80.
29. Ahmad CS, Lee TQ, ElAttrache NS. Biomechanical evaluation of a new ulnar collateral ligament reconstruction technique with interference screw fixation. Am J Sports Med. 2003;31(3):332–7.
30. Conway JE, Jobe FW, Glousman RE, Pink M. Medial instability of the elbow in throwing athletes. Treatment by repair or reconstruction of the ulnar collateral ligament. J Bone Joint Surg Am. 1992;74(1):67–83.
31. Thompson WH, Jobe FW, Yocum LA, Pink MM. Ulnar collateral ligament reconstruction in athletes: muscle-splitting approach without transposition of the ulnar nerve. J Shoulder Elbow Surg. 2001; 10(2):152–7.
32. Armstrong AD, Dunning CE, Ferreira LM, Faber KJ, Johnson JA, King GJ. A biomechanical comparison of four reconstruction techniques for the medial collateral ligament-deficient elbow. J Shoulder Elbow Surg. 2005;14(2):207–15.
33. Rettig AC, Sherrill C, Snead DS, Mendler JC, Mieling P. Nonoperative treatment of ulnar collateral ligament injuries in throwing athletes. Am J Sports Med. 2001; 29(1):15–7.
34. Andrews JR. "Failed" ulnar collateral ligament reconstruction and revision ulnar collateral ligament reconstruction. AOSSM Annual Meeting. Keystone Colorado. 2005.
35. Paletta Jr GA, Wright RW. The modified docking procedure for elbow ulnar collateral ligament reconstruction: 2-year follow-up in elite throwers. Am J Sports Med. 2006;34(10):1594–8.
36. Petty DH, Andrews JR, Fleisig GS, Cain EL. Ulnar collateral ligament reconstruction in high school baseball players: clinical results and injury risk factors. Am J Sports Med. 2004;32(5):1158–64.
37. Dodson CC, Slenker N, Cohen SB, Ciccotti MG, DeLuca P. Ulnar collateral ligament injuries of the elbow in professional football quarterbacks. J Shoulder Elbow Surg. 2010;19(8):1276–80.