Narrative Review Article

Ulnar Collateral Ligament Reconstruction: Epidemiology, Risk Factors, and Evolving Treatment Strategies

Neel R. Gupta

Mountain View High School, 3535 Truman Avenue, Mountain View, California, 94040, United States

ABSTRACT

The Ulnar Collateral Ligament (UCL) is the primary stabilizer of the elbow against valgus stress during overhead throwing motions. Injury rates among young athletes especially have risen sharply in recent years, with male athletes aged 15-19 representing 54% of all UCL injuries, sparking a growing interest in reconstruction and the biology behind it. Although advances in surgical techniques and new biological therapies have become more popular, there are still gaps in our understanding of the optimal treatment for each case. Long term outcomes of new techniques, sex-based differences, and differences in injury patterns all influence the choice of treatment. This review evaluates current evidence on UCL injury management in order to help identify the optimal treatment selection criteria and highlight areas in need of more research. Male athletes are more likely to sustain acute distal tears whereas females are more likely to sustain chronic midsubstance injuries. Surgically, the docking technique remains the gold standard due to high return-to-play rates and fewer complications. However, there are new methods arising such as the interference screw and internal bracing that are showing promise in younger athletes and revision cases. Non-surgical treatments including platelet rich plasma or PRP therapy, physical therapy rehabilitation, and bracing have shown variable outcomes but have been seen to be a viable alternative for partial tears. Future research needs to focus on long-term outcomes of newer surgical techniques, optimization of biological therapies, and clarification of sex-based differences in UCL injury and treatment.

Keywords: Ulnar Collateral Ligament; Surgery; Risk Factors; Epidemiology; Injury; Return to Sport

INTRODUCTION

The Ulnar Collateral Ligament (UCL) is the primary stabilizer against valgus forces (forces that push towards the middle of your body) in the elbow, especially during overhead throwing motions. This structure is located on the medial aspect of the elbow joint and is a complex

tri-bundled ligament with 3 distinct components, the anterior oblique bundle (AOL), posterior oblique bundle (POL), and transverse bundle. The AOL is the primary valgus stabilizer, which consists of 2 bands: an anterior band that provides primary stability with the elbow flexed between 30-90 degrees, and a posterior band that becomes the primary stabilizer when the elbow is flexed between 90-120 degrees (1, 2) The UCL comes from the medial epicondyle of the humerus and inserts on the sublime tubercle of the proximal ulna.

Figure 1 provides an anatomical representation of the UCL's relationship with the elbow joint (3). This creates a strong fibrous connection that is needed for
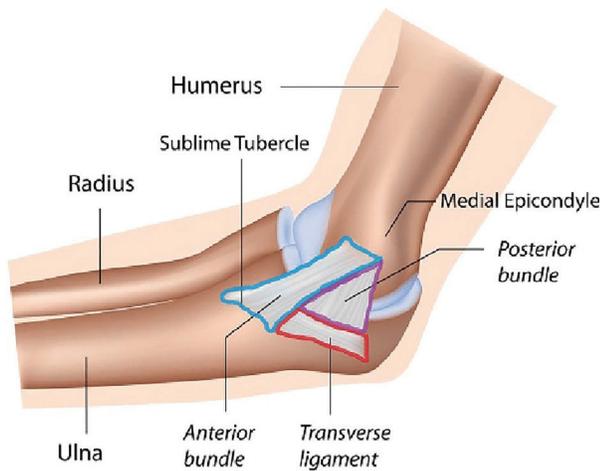
Figure 1. Anatomical structure of the ulnar collateral ligament (UCL) complex of the elbow. This illustration shows 3 distinct bundles: Anterior Oblique Ligament (AOL), Posterior Oblique Ligament (POL), and Transverse Ligament. The AOL is the primary valgus stabilizer, originating from the medial epicondyle of the humerus and inserting at the sublime tubercle of the proximal ulna. The medial view shows the UCL's relationship to surrounding bony structures in the elbow joint (3).

elbow stability while throwing (1, 2). UCL's poor healing capacity can be attributed to its poor vascularization (4). This contributes to approximately 1,935 UCL injuries per year (5).

UCL injuries have been increasing over multiple sports, especially amongst young athletes. In collegiate baseball, surveillance data from 155 NCAA Division I programs showed that 2.5% of all eligible athletes had UCL reconstruction during a single season. (6). In the NCAA, javelin athletes have the highest risk of UCL injury, at 6.69 times greater odds than other sports combined. This can be attributed to the biomechanical demands of the sport, as athletes are generating angular velocities around 1900 degrees per second (7) Baseball players also have elevated risk of 1.55 times the odds of other sports (7, 8). The next most at risk sport is gymnastics, particularly among female athletes and weight bearing activities (9). This is likely due to the loading patterns in gymnastics because of how the elbow has to handle the valgus stress during the motions that gymnasts go through, putting a large amount of weight on their elbow joints and ligaments. This leads to acute tears or avulsions instead of chronic injuries occurring such as those in throwing athletes. Male patients aged 15-19 years old account for 54% of all UCL injuries

(5). However, athletes aged 20-24 years old have the highest rates of UCL reconstruction, representing 25% of all procedures, even though they only represent 18% of total injuries (5). Seasonal patterns show that injury peaks align with competitive baseball seasons, with rates peaking during April-May and September-October (10).

The treatment of UCL injuries through surgery has been influential in all sports. This began when Los Angeles Dodgers Pitcher Tommy John suffered a career ending elbow injury during a game against the Montreal Expos. Then, Dr. Frank Jobe, who was the Dodgers team physician and orthopedic surgeon, diagnosed Tommy John with a complete UCL rupture. He convinced John to undergo an unprecedented surgical solution after being instructed to "make something up to fix his elbow" (11). The procedure that was performed involved harvesting a tendon from John's Wrist, the palmaris longus and using that to reconstruct the torn UCL through a figure-of-eight pattern of graft configuration (12). Dr. Jobe created bone tunnels in the ulna and humerus to secure the graft, helping to establish the technique that became known as the Jobe technique. Which changed injury management in baseball and other sports forever.

Even though it is not widely used today, it set the precedent for UCL surgery. This review evaluates current evidence on UCL injury epidemiology, risk factors, and treatment strategies in order to identify optimal treatment selection criteria and highlight areas requiring further investigation.

Biomechanics and Quantification of Throwing Motion

Overhead throwing motion can be compared to a sequential transfer of energy from the lower extremity through the kinetic chain to the arm and then the ball (13). This process starts with ground forces generated from your legs, this transfers energy through the pelvis, trunk, scapula, shoulder, then to the elbow and hand (3, 14). A 20% decrease in kinetic energy from the hip and trunk musculature requires a 34% increase in rotational velocity of the shoulder complex to reach the identical force to the hand and then the ball (15). This relationship has implications for injury risk because when lower body mechanics are compromised due to fatigue or poor conditioning the elbow has to compensate by absorbing more stress. This could go on to explain the seasonal injury patterns that are observed with peaks at the beginning of the season and at the end. However, prospective studies directly linking lower extremity deficits to UCL injury risk are limited.

The throwing motion consists of 6 different phases.

These are the wind-up, early cocking, late cocking, acceleration, deceleration, and follow-through. The max valgus stress occurs during the late cocking to early acceleration phases (16). This tends to happen when the elbow is positioned at approximately 87-90 degrees of flexion (14, 17). This is when the medial elbow experiences the forces that exceed the limits of the UCL's physiology.

Biomechanical studies have shown that the forces during throwing surpass the load that the UCL can manage. The medial elbow experiences around 60 Newton-meters of torque and acceleration, reaching up to 2700 degrees per second during the throwing motion (13). Professional pitchers reach 64 Nm of valgus stress per pitch, whereas youth experience less than half of that at 28 Nm per pitch; high school pitchers reach 48 Nm whereas collegiate pitchers rise to 55 Nm (18, 19). However, despite these readings of elbow stress, cadaveric studies have shown that the UCL will fail at around 32-34 Nm of valgus stress (14, 19).

The difference between the force applied and the maximum ligament strength is kept in balance by dynamic stabilization given by the flexor-pronator mass, triceps, anconeus, and coordinated shoulder internal rotation (14, 16, 20). The protective mechanisms of these dynamic stabilizers have been proposed to account for this discrepancy between cadaveric failures and valgus elbow stress during pitching motions. The flexor-pronator muscle mass generates a varus torque that helps to counteract valgus stress, which triceps and anconeus contribute through joint compression and stability (14, 20). The protective capacity of these dynamic stabilizers can be compromised by many factors like muscle fatigue and inadequate conditioning or poor throwing mechanics. (14, 20) This biomechanical issue, where forces routinely exceed ligament failure thresholds, yet injuries don't occur with every pitch, shows another gap in our understanding. While dynamic stabilizers play a protective role, the mechanisms and their variability in individuals remain incompletely understood. This has important implications in injury prevention: strengthening programs targeting these stabilizers could be important along with pitch count restrictions, however prospective studies showing that these interventions reduce injury are scarce.

Risk Factors

Through the years, research has shown modifiable and non-modifiable risk factors associated with UCL injuries. These can be classified into workloads, development, and anatomy.

Pitch counts and the amount that an athlete is throwing is the most easily modified risk factor that have been seen in current injury prevention methods (10). Specifically pitch count affecting UCL integrity should be attributed to high effort pitches (21). However, even more specifically, data has shown that pitch quality and effort seem to be more important than the total pitch quantity in UCL injuries. Seasonal patterns show that most athletes get injured at the beginning and end of the baseball season (10). We can conclude that this is because of inadequate preparation and rapid progressions for the early peak, then for the later peak it is because of fatigue and overuse.

Pitch velocity is the most consistently reported predictor of UCL injury across different studies (18, 22, 23, 24). In a comprehensive analysis of MLB pitchers, peak pitch velocity was higher in pre-injury pitchers in comparison to controls. These numbers were 93.3 mph versus 92.1 mph. It shows a clear relationship with 20% of pitchers throwing over 95.7 mph needing UCL reconstruction, whereas only 7.8% needed the same treatment with peak velocities under 86.9 mph (22). These ideas reinforce the impact of pitch velocity on the integrity of the UCL due to the relationship between throwing and elbow valgus stress. Studies show a correlation with fastball velocities and varus torque regarding the elbow (24). In order to mitigate injury risks going forward, high velocity pitchers such as that of the typical "closer" role should be limiting pitch counts to reduce injury risk. However, it is still unclear if velocity itself is causative or a marker for other risk factors. Pitchers throwing harder might throw more frequently in higher leverage situations, have higher workloads, or have mechanic struggles that create high velocity and more elbow stress. This distinction is important for prevention because if velocity correlates with other factors like mechanics or excessive workload, then interventions that target those underlying issues will be more effective than velocity restrictions. Prospective studies are needed to control these confounding variables

Bad pitching mechanics is also a significant modifiable risk factor for UCL injuries, along with overuse. These poor mechanics increase the valgus stress on the elbow and elevate the injury risk along with other risk factors that could be at play. Three specific mechanical flaws have been associated with potential UCL injury: the "Tommy John Twist", open front landing foot, and early swinging gate of the hips. The Tommy John Twist refers to excessive shoulder horizontal abduction during the

cocking phase, which puts more stress on the elbow. The open front landing foot occurs when the landing foot is positioned outwards rather than towards home plate. The early swinging gate of the hips occurs with premature hip rotation before the arm reaches its proper throwing position (25). These disrupt the previously stated kinetic chain transfer of energy, which increases elbow stress to compensate. This can similarly be seen with any decreased efficiency in the lower extremities during throwing as the body compensates with excessive force through upper extremity joints to reach an identical velocity (15).

Early sports specialization in baseball can be seen as a risk factor for UCL injury and other overuse injuries as well. This means committing to a sport and training year-round for that sport exclusively. Professional baseball players who participated in multiple sports in high school show lower rates of upper and lower extremity injuries, resulting in playing more major league games than those who specialized. Similarly, single sport pitchers showed higher rates of shoulder and elbow injuries along with reinjury rates (26). The mechanisms for this to cause injury risk can be attributed to a lack of opportunity to develop the proper neuromuscular skills and fitness to protect against injury and that multisport athletes benefit from this training through sports other than baseball (26).

There are many risk factors for UCL injuries that cannot be modified. Age is one of these, as younger players are at higher risk due to immature bones and ligaments. Additionally, anatomical factors like ligament thickness and joint laxity are non-modifiable factors that influence UCL injury risk (27).

Studies have shown that the UCL thickness is significantly greater in the throwing arm than non-throwing arm. Specifically, 0.618 mm versus 0.581 mm, and also greater in pitchers than non-pitchers (21) This accounts for thinner UCLs needing to strengthen the muscles around their elbow more in order to reduce injury.

The last main risk factor that will be mentioned is body mass index (BMI) and weight. This has been identified as an independent risk factor for UCL injury. The percentage of pitchers that need UCL reconstruction increases as BMI goes up (21). This can be due to more forces generated by larger athletes or the biomechanical disadvantages of higher body mass.

Clinical Presentation

The clinical presentation of UCL injuries can be classified into the categories of Acute or Chronic presentation. Acute UCL injuries are usually associated with a pop or snap sensation in the elbow while throwing or performing an overhead motion (28). Pain is often described as immediate and severe along the inner elbow, preventing additional throwing or overhead valgus stress. The presentation is likely to be followed by instability in the elbow and as stated before, inability to resume athletic activity using the respective injured appendage. In most cases pain is centralized in the medial epicondyle and could radiate along the UCL complex (29). Most other times the UCL injury is presented as a chronic overuse injury from repetitive microtrauma. Athletes report a gradual onset of medial elbow pain. At first this starts immediately after throwing motions but eventually worsens to take effect during rest periods as well (28). Symptoms to note are: progressive loss of velocity, medial elbow pain during late cocking and early acceleration phases, pain consistency, elbow limited range of motion, and neurological symptoms.

Physical Exam

Physical examination of UCL injuries requires a systematic approach that includes inspection, palpation, range-of-motion (ROM) assessment, and the use of targeted provocative maneuvers. Examination should always involve bilateral comparison and assessment of surrounding anatomical structures to identify asymmetry or compensatory findings.

Initially, evaluation focuses on tenderness and swelling along the medial aspect of the elbow, particularly at the UCL insertion sites. Palpable tenderness over the medial epicondyle and medial joint line demonstrates a sensitivity of 81–94% but a relatively low specificity of approximately 22% for UCL tears (30). Additional features to assess include swelling, bruising, and visible deformity, which are typically more pronounced in acute injuries and may be subtle or absent in chronic presentations. Following inspection and palpation, the valgus stress test is commonly performed to assess UCL integrity. This test is conducted with the patient in a seated or supine position, the elbow flexed to 20–30 degrees, and the forearm supinated. The examiner stabilizes the distal humerus with one hand while applying a valgus force to the elbow with the other (31). A positive test is indicated by the absence of a firm endpoint, medial joint opening greater than 1 mm on fluoroscopic assessment, or reproduction of pain. The valgus stress test demonstrates a sensitivity of approximately 66% and a specificity of 60% for diagnosing UCL injuries (30).

To improve diagnostic accuracy, the Moving Valgus Stress Test (MVST) is frequently employed. This test is performed with the patient upright and the shoulder abducted to 90 degrees (32,33). While maintaining shoulder external rotation, a moderate valgus torque is applied to the fully flexed elbow, which is then rapidly extended to approximately 30 degrees. A positive test requires reproduction of the patient's medial elbow pain, with maximal discomfort occurring between 120° and 70° of elbow flexion. The maneuver should be repeated in the reverse direction to confirm findings. When compared with surgical exploration or arthroscopic assessment, the MVST demonstrates a sensitivity of 100% and a specificity of 75%, making it one of the most accurate clinical tests for UCL injury diagnosis (32,33). In addition, the Milking Maneuver specifically evaluates the anterior bundle of the UCL (34). It is performed with the patient seated or standing, the shoulder externally rotated, and the elbow flexed beyond 90 degrees. The examiner applies valgus stress by pulling laterally on the patient's thumb while palpating the medial joint line. A positive result is indicated by pain, apprehension, or a sense of instability. A modified version of the Milking Maneuver is performed with the arm positioned at approximately 70 degrees of elbow flexion, shoulder abduction, and maximal external rotation (35). This variation is considered more sensitive for detecting UCL pathology and is therefore more commonly used in clinical practice.

Finally, additional provocative tests may be used to assess elbow instability and associated pathology. The lateral pivot-shift test is performed with the patient supine, the elbow extended, and the arm positioned overhead. Supination torque, valgus stress, and axial compression are applied while the elbow is flexed (36). A positive result is characterized by subluxation of the radial head followed by spontaneous reduction during flexion. Functional assessments, such as the chair push-up test or prone push-up test, may also be used; reproduction of pain, apprehension, or instability during these maneuvers suggests ligamentous insufficiency (37).

Imaging

Different imaging modalities provide complementary information regarding severity, location, and type of UCL injury. Accordingly, a combination of imaging techniques is often required for comprehensive evaluation. The most commonly used modalities include plain radiography, magnetic resonance imaging (MRI), magnetic resonance arthrography (MRA), and ultrasonography.

Initially, plain radiography is typically obtained to rule out fractures or dislocations; however, it offers limited visualization of soft tissue structures such as ligaments. Nevertheless, in chronic UCL injuries, radiographs may reveal heterotopic ossification or calcification within the ligament substance (38).

In contrast, magnetic resonance imaging (MRI) provides a more detailed assessment of ligament morphology and signal characteristics (39). MRI allows for classification of UCL injuries based on both location (proximal, midsubstance, or distal) and severity. The Ramkumar six-stage system categorizes injuries by location and degree of disruption (38), while the four-grade classification system defines: grade I as an intact ligament, grade II as low-grade signal change without tearing, grade III as high-grade signal change or partial tearing, and grade IV as complete ligament disruption (39).

To further enhance diagnostic accuracy, magnetic resonance arthrography (MRA) may be employed, particularly for detecting partial-thickness tears. This technique involves intra-articular injection of a gadolinium-based contrast agent followed by immediate MRI acquisition (40). MRA demonstrates approximately 95% sensitivity for complete UCL tears and 86% sensitivity for partial tears (41), making it especially valuable for identifying subtle injuries that may be overlooked on conventional MRI.

In addition to MRI-based modalities, ultrasonography plays an important role in the evaluation of UCL injuries because it allows real-time, dynamic assessment in a cost-effective manner. High-frequency linear transducers (10–15 MHz) are typically used to achieve optimal resolution (42). During examination, the patient is positioned supine with the shoulder abducted to 90 degrees, the elbow flexed to 30 degrees, and the forearm in neutral rotation, allowing optimal visualization of the anterior bundle of the UCL (42, 43). Static ultrasound findings suggestive of UCL injury include ligament thickening or thinning, hypoechoic regions within the ligament, disruption of normal fibrillar architecture, or discontinuity between proximal and distal ligament fibers (42).

Furthermore, dynamic stress ultrasonography expands diagnostic capability by allowing functional assessment of ligament integrity. During this examination, valgus stress is applied while imaging the UCL, and medial joint space widening is measured to differentiate complete tears from ligament insufficiency (44, 43). Compared with static imaging alone, dynamic ultrasound demonstrates superior diagnostic accuracy by directly evaluating ligament behavior under load.

Finally, in the postoperative setting, magnetic resonance arthrography is commonly used to assess the integrity of reconstructed UCLs (45). Following reconstruction, the ligament typically appears thicker and more heterogeneous than native tissue and is anchored more distally at the sublime tubercle. The presence of contrast extravasation into the reconstructed ligament fibers is indicative of graft failure or compromise (40, 46).

Autografts Versus Allografts

There are two major surgical reconstruction grafting options for UCL injury, autograft and allograft. For autografts, the tissue is harvested from the patient's own body and transplanted to another location. For UCL reconstruction, this involves the palmaris longus tendon from the forearm and gracilis or hamstring from the thigh (47). For allografts, the UCL is transplanted from a deceased donor into a recipient. (48, 49). The most common choice for UCL reconstruction is autografts, representing 92% of procedures (47). The palmaris longus tendon is the most frequently selected graft accounting for about 64% of all reconstructions (47).

There are many benefits of an autograft. Because the tissue comes from the patient, there is reduced risk of immune rejection or disease transmission (50, 51). The tissue is also incorporated faster into the recipient site because it is from the patient, so blood vessels and cells grow into the graft quicker (52). Both the palmaris longus and hamstring autografts have shown return to sport rates of 84.6% and 80.8%, respectively (50). The revision rate for autograft reconstruction is low at 1.8% (47). Drawbacks of autografts include the creation of a secondary surgical site and need for healthy tissue. Complications occur in 1-4% of cases. These complications include infections, saphenous neuritis from hamstrings, and donor site scar tenderness (48, 49). Autografting also increases the operative time and surgical complexity. Surgeons have to make more incisions and avoid nerve injuries, while managing different surgical sites. This increases risk of complications, and the time patients are under anesthesia.

Allografts have the benefit of eliminating the donor site complications and morbidity (48, 49). Patients do not have pain, weakness, or complications at the alternate surgical site of an autograft. This can help athletes who are worried about weakening their other structures contributing to performance. In turn, this reduces the time of operation and incisions and their size (53). This means less anesthesia, risk, and recovery. Allografts are commonly used when autograft sources have been exhausted or multiple procedures are needed. There is a 2.6% overall revision rate after primary construction, which is inferior to the autograft revision rate (47). Drawbacks of the allograft are higher revision rates, which can be attributed to the slower tissue incorporation because it is foreign. Also weakening of the tissue and the sterilization of both procedures could cause the biomechanical properties of the tissue to change. It is also important to note how allografts are considerably more expensive than autografts because of the procurement, processing, testing, and storage provided by tissue banks. This limits accessibility.

Allografts have a higher risk of disease transmission, though still only representing 1 in 120,000 cases (53). Recent comparative studies are showing similar functional outcomes between autograft and allograft UCL reconstructions (54, 49)

Surgical Techniques

The Jobe technique, first described by Dr. Frank Jobe in 1974 during the reconstruction of Tommy John's UCL (55), uses an autograft that is woven in a figure-of-eight configuration through bone tunnels in the ulna and humerus. The autograft is usually the palmaris longus found in the forearm.

During the surgical process, the Flexor-pronator mass is detached, and large bone tunnels are drilled for the graft to be woven in a figure-of-eight pattern (56). Ulnar nerve transposition is performed to prevent neuropathy and reduce complications. Some drawbacks to this method that have been discovered include a high complication rate of approximately 20%, as well as soft tissue dissection and muscle detachment, which can prolong recovery time. Clinical outcomes of this method result in around 63% return to play rate (55). However, this method in its pure form is rarely used today. Figure 2 shows an illustration of the job technique in relation to UCL reconstruction (56).

The modified Jobe technique refines the original Jobe technique described above. The goal of this refinement was to reduce soft tissue trauma and complications. Instead of detaching the flexor-pronator mass, the surgeon splits it along the lines of the muscle fibers. (12) Ulnar nerve transposition is only performed when necessary and is not a routine part of this method. It still adopts the same figure-eight graft configuration as the original Jobe technique. This method causes less soft tissue damage, which in turn leads to shorter recovery times, decreased risk of ulnar neuropathy, and strong graft fixation.
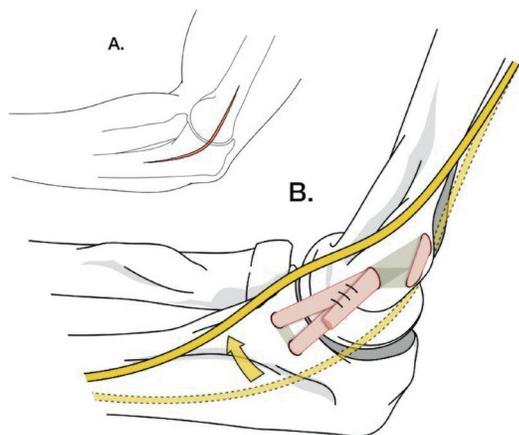
Figure 2. Illustration of the Jobe technique for UCL reconstruction. The original method was developed by Dr. Frank Jobe, involves weaving an autograft of a palmaris longus tendon in a figure of eight configuration through bone tunnels in the ulna and humerus. This technique needs a detachment of the flexor-pronator mass and routine ulnar nerve transposition. However, this method has been mostly replaced by more modern methods like the docking technique, however it still served as a foundation for UCL reconstruction surgery (56).

However, it still requires relatively large bone tunnels and may involve more dissection than modern alternatives. Clinical results indicate a ~75–90% return-to-play rate and a decreased complication rate of 5–10% (57, 58). This method is still somewhat used today and remains widely respected.

Next, the most widely used and most successful method today is the Docking Technique. This method was introduced to simplify graft fixation and reduce complications. It uses the same muscle-splitting approach as the modified Jobe technique and only transposes the ulnar nerve if necessary. The graft is passed through tunnels in the ulna and then "docked" into a single socket on the humerus.

Sutures attached to the graft exit the bone proximally and are tied down to fix the graft in place securely. The benefits of this technique include smaller bone tunnels, strong and reproducible graft fixation, and reduced soft tissue dissection (29). One drawback is the limited surface area for graft healing on the humeral side compared to figure-eight techniques. Clinical outcomes indicate an 85–95% return-to-play rate in elite athletes, with lower complication and revision rates than traditional Jobe-based techniques (59, 60). As a result, the Docking Technique has become the most commonly used standard method for UCL reconstruction today.

However, the presumed superiority of the docking technique is because of retrospective case studies and surgeon experience instead of high-level comparative trials. Most studies reporting this method lack control groups and don't have detailed long follow up periods. These trials are more subject to selection bias that favors healthier athletes. Also, return to play rates might not reflect return to a performance level pre-injury and long-term data on durability for the past 5 years is limited.

Figure 3 shows Ulnar Collateral Ligament (UCL) reconstruction with the novel anatomic UCL reconstruction technique. (A) The graft is fixed into a socket on the humerus via adjustable loop fixation. (B) All-suture suture anchors are placed in the ulna and (C) tied to secure the graft at the proximal UCL footprint. (C) A looped suture is used to run a whipstitch in the graft, and this suture is loaded onto a cortical button, (D) which is secured at the distal aspect of the native UCL footprint (61).

The use of an interference screw for UCL reconstruction is a relatively recent innovation, drawing on techniques from ACL surgery. It secures the graft
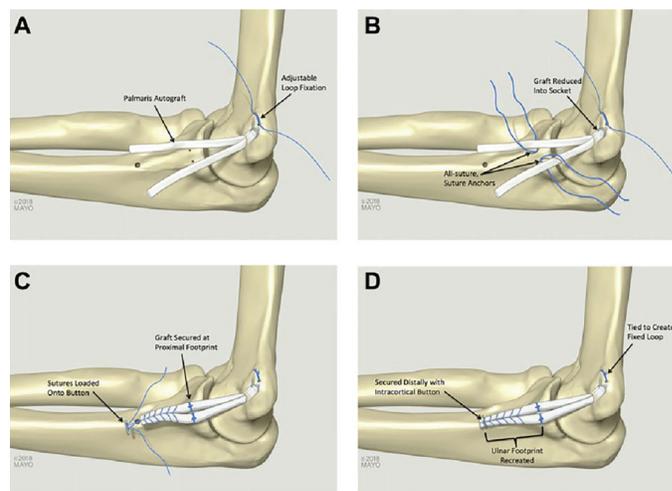
Figure 3. Docking Technique model with 4 distinct phases A,B,C,D. The Graft is fixed into a humeral socket using adjustable loop fixation as shown in phase A. All suture anchors are placed in the ulna at the proximal UCL footprint as shown in phase B. The anchors are then tied to secure the graft as shown in phase C. Finally, a looped suture with whipstitch configuration is loaded onto a cortical button, before being secured at the distal aspect of the UCL footprint. This technique is currently the best available method, offering strong fixation with smaller none tunnels and less soft tissue trauma compared to previous methods (61).
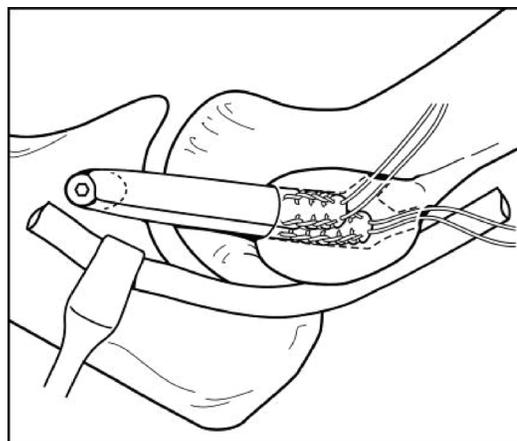
directly into bone tunnels in both the ulna and humerus using bioabsorbable or metallic interference screws, eliminating the need for sutures or docking (62, 63). This method is frequently paired with internal brace augmentation, acting like a "seatbelt" for the graft, to provide additional support during healing (64, 65). Benefits include rigid fixation, simplified graft placement, and compatibility with internal bracing (62, 65). However, there are biomechanical concerns regarding graft–screw interface failure, graft laceration, and tunnel widening (62). Clinical outcomes report 85–90% return-to-play rates, comparable to docking techniques, with favorable results in younger athletes and revision cases (66, 67). Despite being a newer method with limited long-term data, early studies indicate strong potential as a preferred treatment in selected populations. But these outcomes are based on small case series that are usually under 50 patients, and little follow up. They lack direct head-to-head comparisons with docking techniques and the biomechanical concerns with graft-screw interface failure have not been adequately studied. These can include graft lacerations during screw insertions and tunnel widening in the ulna. Also, the optimal screw type, whether bioabsorbable or metallic, and patient selection criteria have not been strongly defined in studies, so this technique cannot be standardized.

Figure 4 shows us an illustration of the use of an interference screw in UCL reconstruction of the elbow joint (68). Figure 5 shows us a similar illustration of the use of internal bracing within the elbow joint, to stabilize the UCL in operative reconstruction (69).

Non-surgical Techniques

Non-surgical injury management plays an equally important role in the treatment of partial ulnar collateral ligament tears. It's used as an initial treatment for early injuries, specifically when imaging reveals no complete tear of the ligament. Patient selection plays a crucial role in determining the outcome. Success is most apparent when the tear is proximal or distal, rather than in the midsubstance, which tends to have poorer healing potential (59).

PRP or Platelet-Rich Plasma therapy has gained popularity as a regenerative option for UCL injuries. It's been explicitly seen among athletes who are hoping to avoid or delay their surgery. This technique involves centrifuging the patient's blood to isolate their platelet-rich plasma. This plasma contains growth factors that can promote soft tissue healing. Then this plasma is injected under ultrasound guidance directly into the site

Figure 4. *Illustration of interference screw fixation for UCL reconstruction surgeries. This technique is adapted from ACL surgery principles, using bioabsorbable or metallic interference screws in order to secure the graft directly into the bone tunnels in both the ulna and humerus. The screw compresses the graft against wall tunnels and provides rigid fixation without needing sutures or docking. This method is commonly combined with internal brace augmentation and shows promise in younger athletes and revision cases (68).*

Figure 5. *Internal bracing augmentation technique for UCl stabilization. The internal brace acts as a protective stabilizer for the healing ligament or graft, giving additional mechanical support during the rehabilitation phases of recovery. A high strength suture tape is secured along the native or reconstructed UCL, spanning from the medial epicondyle to the sublime tubercle. This reinforcement could allow for earlier return to activity while protecting healing tissues from excessive valgus stress (69).*

of the partial UCL tear (70). Several studies have reported promising results with PRP, particularly in throwing athletes with grade 1 or 2 sprains. In the Podesta *et al.* study (2013), 34 professional baseball players were treated with PRP injections and a structured rehabilitation program. ~88% of athletes returned to play at the same or higher level, with minimal complications (70).

Additionally, Dines *et al.* (2016) observed that early PRP injections, when combined with rehabilitation, improved healing rates and shortened recovery times. However, the outcomes have been shown to depend on multiple factors. For instance, proximal/distal tears treated with PRP result better than the midsubstance tears. The chronicity of the injury also plays a crucial role, as it may require surgery for full healing. Other factors, such as the composition of PRP and timing/number of injections, are less important but can still alter the course of treatment. Critical evaluation of the PRP literature available shows significant methodological limitations that complicate the interpretation of findings. Studies are widely varied in PRP preparation protocols, with platelet concentration, leukocyte content, and activation method. Most published studies appear to be small and retrospective without controls or standard rehabilitation groups, so no conclusions can be drawn from PRPs independent effect. The reported success rates from 42-88 % (81) likely are due to publication bias, with negative results being underreported. It is also known that biological mechanisms in which PRP could enhance UCL healing is still poorly understood so it is hard to draw effective conclusions about PRP treatment.

An evidence-based rehabilitation program can be essential in the effectiveness of non operative treatments for UCL injuries. These physical therapy programs can be used as a standalone treatment or in conjunction with PRP. Goals of the program often include strengthening dynamic stabilizers of the elbow, specifically the flexor-pronator mass and improving scapular control, core stability, and lower body strength, and correcting any biomechanical inefficiencies in the throwing motion. The rehabilitation programs often have 3 independent phases consisting of an Acute Phase, Strength Phase, and Throwing Phase. Specifically, the Acute phase focuses on rest, controlling inflammation, and restoring range of motion. The Strength phase is concentrated in progressively loading the forearm and shoulder girdle, with exercises focusing on scapular, rotator cuff, and forearm strengthening. The Throwing phase is when a gradual return to the throwing program is implemented. This program consists of progressive distance increases between throws over 3-6 months (71). The non-operative management is effective for specific partial UCL tears; however, the outcomes are mixed. RTP rates range from approximately 42% with rehab alone to 79 to 80% when including PRP or bracing. Timeline for non-operative recovery is 3 to 4 months compared to 12 to 18 months for surgical reconstruction (72). The large variability in outcomes suggests that current evidence is unable to predict which patients would be benefitting from non-operative treatment. Most studies are lacking validated patient selection criteria, which makes it hard to counsel athletes on likelihood of success. Although tear location and chronicity are important, the precise thresholds and combinations of factors predicting success are not defined clearly. Also, the definition of success is varied across studies, as some report returning to any level of play while others require return to pre-injury performance. This complicates interpretations and comparisons of data. Prospective studies with standard outcome measures and patient selection criteria defined are needed to guide future treatment decisions.

Another non-operative treatment of UCL injuries is bracing. Functional elbow braces limit the valgus stress on the elbow during throwing motions. The braces are specifically beneficial during the early phases of rehab or when athletes are beginning a throwing progression during the throwing phase of their physical therapy. Although bracing does not promote healing, it can provide external support to reduce strain on a healing ligament, enhance psychological confidence for athletes returning to high-stress movements, and allow for the gradual reintroduction of valgus loads in a controlled manner. Camp *et al.* (2017) suggests that bracing, when used in conjunction with rehabilitation and/or biologics such as PRP, can help protect healing tissue and reduce reinjury rates. Newer brace designs are more lightweight and allow functional motion. Use should be temporary and progressive, as over-reliance may reduce proper muscle engagement. Unlike other ligament injuries, orthotics are not commonly used for UCL injuries but could be prescribed if concurrent wrist/hand biomechanical issues are contributing to elbow valgus stress.

Table 1 provides a comprehensive comparison of all treatment techniques discussed, including surgical approaches like the Jobe, Modified Jobe, Docking, and Interference Screw. It also includes non-surgical options like PRP, physical therapy, and bracing. There are side by side comparisons of return to play rates, recovery times, and key benefits, limitations, and ideal patient profiles for each approach stated.

Table 1. *Comprehensive comparison of surgical and non-surgical treatment modes for UCL injuries. The table compares 8 treatment approaches including traditional surgical techniques, non-operative biological therapy, rehabilitation therapies, and mechanical support. For each technique the table describes graft type, fixation method, return to play rates, recovery timelines, benefits, limitations and risks, and ideal patients for the treatment option. Data compiled from multiple studies is referenced throughout this review.*

Technique	Type	Graft Fixation	Muscle Handling	Return-to-Play Rate	Recovery Time	Key Benefits	Limitations / Risks	Ideal Patient Profile
Jobe Technique	Surgical	Figure-of-eight sutured through bone tunnels	Detachment of flexor-pronator mass	~75–85%	12–18 months	Strong fixation, historical benchmark	Higher ulnar neuropathy, longer recovery	High-demand athletes, historical context
Modified Jobe	Surgical	Figure-8 with bone tunnels	Muscle-splitting	~80–90%	~12 months	Less soft tissue damage, fewer complications	Larger bone tunnels, more dissection than modern	Athletes seeking traditional techniques with lower risk
Docking Technique	Surgical	Docked graft + sutures	Muscle-splitting	~85–95%	9–12 months	Strong fixation, smaller tunnels, reproducible	Less healing surface on the humerus	Most commonly used in elite athletes
Interference Screw	Surgical	Bioabsorbable or metal screws	Muscle-splitting	~85–90%	9–12 months	Rigid fixation, less complex, internal brace compatible	Graft-screw interface risks, a new method	Younger athletes, revisions, brace users
PRP Therapy	Non-surgical	N/A	N/A	~50–70%	3–6 months	Minimally invasive, promotes healing	Variable success, only for partial tears	Partial UCL tears, low-demand athletes
Physical Therapy	Non-surgical	N/A	N/A	~60–80%	3–6 months+	Strengthens the kinetic chain, non-invasive	Lower RTP than surgery, patient compliance dependent	Low-demand athletes, early-stage injuries
Bracing/ Orthotics	Non-surgical	N/A	N/A	N/A	Ongoing	Prevents valgus stress, supports the elbow	Doesn't repair ligament, only supportive	Throwers in season, or combined with rehab

Sex-Based Differences in UCL Injuries

A retrospective review of 1,068 UCL injuries revealed statistically significant differences between male and female athletes in terms of tear location, injury onset, and MRI findings (73). Females were more frequently presented with chronic injuries and midsubstance partial UCL tears, whereas male athletes more often sustained acute tears with bony edema or distal ligament damage (73).

The mechanisms behind these sex-based differences are still poorly understood and show a mix of biological, biomechanical, and participation factors. Females have smaller ligament size, different collagen fiber composition, and hormone differences that influence ligament laxity and injury patterns. Specifically, estrogen receptors have been identified in ligamentous tissue and

the menstrual cycle could have an effect on ligament's mechanical properties, however direct evidence linking hormonal variation to UCL injury is lacking. However, sport specific factors might be equally or even more important. Most acute distal tears in males versus chronic midsubstance tears in females could be reflected by different mechanisms of injury. Males usually sustain UCL injuries through high velocity overhead throwing motions from baseball and javelin, whereas females commonly injure UCLs through weight bearing activities like gymnastics or different throwing mechanics from softball. These sport specific differences that play into sex differences, could explain differences in tear location and chronicity rather than the biological sex differences.

In terms of return-to-sport outcomes in females, a systematic review focused on UCL repair and reconstruction specifically in female athletes reported good outcomes, with approximately 87% returning to sport at an average of 2 years post-procedure (74). Functional scores were high and did not differ significantly between those receiving internal-brace repairs and those receiving standard repairs (74).

These findings have important implications for specific treatment focuses. The higher rate of midsubstance tears in females could favor surgical reconstruction instead of repair, because of the poor healing potential in the midsubstance. In contrast, the presence of acute distal tears in males would make them better candidates for primary repair with internal bracing. However, current treatment doesn't incorporate sex-based differences and most surgical outcome studies are predominantly male. Future research needs to prioritize prospective studies including female representation, while comparing injury mechanisms and treatment outcomes based on sex. Understanding whether observed differences come from biology, sport specific interactions, or training practices will be extremely important to optimize patient-care for athletes.

Return-to-Play Criteria and Assessment

Return-to-Play (RTP) criteria after injury is critical for minimizing reinjury and ensuring safe resumption of athletic activities. However, RTP criteria are varied across studies and clinical settings, which complicates the interpretation of reported RTP rates. Most protocols incorporate both objective clinical measures and sport specific benchmarks. RTP clinical measures after injury usually involve assessment of range of motion, strength restoration, and absence of valgus instability (71, 72). However, some studies report return-to-play at any level of competition, whereas others require return to pre-injury performance, which significantly affects reported success rates. These inconsistencies complicate comparison of different treatment outcomes and show a need for a standardized RTP definition and criteria in future research.

CONCLUSION

UCL injuries represent a growing concern across many different sports, with high rates among baseball players and young athletes. This review highlights that risk factors are multifaceted, ranging from modifiable elements like pitch velocity, mechanics, and workload, to non-modifiable aspects like anatomy, age, and sex differences. Advances in imaging, specifically in dynamic ultrasound and MR arthrography have improved diagnostic accuracy guided treatments. While non operative treatments like PRP therapy and structured rehabilitation can be effective in partial tears, surgical reconstruction remains the best and most viable option for complete rupture, with the docking technique being the most reliable.

The implications of these findings stretch beyond surgical management. Recognizing early risk factors and implementing preventive strategies like workload monitoring, pitch count regulation, and biomechanical corrections can help to reduce injury rates in young athletes. For clinicians, tailoring treatment based on patient age, performance demands, and tear characteristics is important. Future studies should emphasize biologics, surgical innovation, and sex specific injury patterns which can help to further refine management strategies. Specifically, longitudinal experiments evaluating the chronic effects of new surgical and nonsurgical treatments for UCL injuries will help clinicians add to their lists of viable treatment options. Ultimately, integrating prevention with evidence-based treatment will help improve outcomes, increase the time of an athlete's career, and reduce the long-term stress on the UCL, helping to avoid injury.

CONFLICT OF INTEREST

The author declares that there are no conflicts of interest related to this work.

REFERENCES

1. Zaremski JL. Elbow Ulnar Collateral Ligament Injuries in Overhead Athletes: An Infographic Summary. *Sports health*. 2022; 14 (4): 527–529. https://doi.org/10.1177/19417381221098622

2. Vaswani R, White A & Dines J. Medial Ulnar Collateral Ligament Injuries in Contact Athletes. *Current reviews in musculoskeletal medicine*. 2022; 15 (6): 474–482. https://doi.org/10.1007/s12178-022-09785-0

3. Zaremski JL, Vincent KR & Vincent HK. Elbow ulnar collateral ligament: injury, treatment options, and recovery in overhead throwing athletes. *Current Sports Medicine Reports*. 2019; 18 (9): 338-345. https://doi.org/10.1249/JSR.0000000000000629

4. Walker MA. Ulnar collateral ligament injury in overhead throwers. Logan University. 2012, November 30. https://www.logan.edu/mm/files/LRC/Senior-Research/2012-dec-41.pdf

5. Solomito MJ, Kostyun RO, Sabitsky JT & Nissen CW. Trends in Ulnar Collateral Ligament Injuries and Surgery From 2010 to 2019: An Analysis of a National Medical Claims Database. *Orthopaedic journal of sports medicine*. 2024; 12 (11): 23259671241290532. https://doi.org/10.1177/23259671241290532

6. Rothermich MA, Conte SA, Aune KT, Fleisig GS, *et al*. Incidence of Elbow Ulnar Collateral Ligament Surgery in Collegiate Baseball Players. *Orthopaedic journal of sports medicine*. 2018; 6 (4): 2325967118764657. https://doi.org/10.1177/2325967118764657

7. Wallace S, Ober J & Devaney L. Return to Sport Criteria and Outcomes in Javelin Athletes Following Ulnar Collateral Ligament Reconstruction: a Systematic Review. *International journal of sports physical therapy*. 2025; 20 (7): 931–942. https://doi.org/10.26603/001c.141277

8. Li NY, Goodman AD, Lemme NJ & Owens BD. Epidemiology of Elbow Ulnar Collateral Ligament Injuries in Throwing Versus Contact Athletes of the National Collegiate Athletic Association: Analysis of the 2009-2010 to 2013-2014 Seasons. *Orthopaedic journal of sports medicine*. 2019; 7 (4): 2325967119836428. https://doi.org/10.1177/2325967119836428

9. Nicolette GW, Gravlee JR. Ulnar collateral ligament injuries of the elbow in female division I collegiate gymnasts: a report of five cases. *Open Access J Sports Med*. 2018; 9: 183-189 (2017) https://doi.org/10.2147/OAJSM.S159624

10. Carr JB, 2nd, Wilson L, Sullivan SW, Poeran J, *et al*. Seasonal and monthly trends in elbow ulnar collateral ligament injuries and surgeries: a national epidemiological study. *JSES reviews, reports, and techniques*. 2021; 2 (1): 107–112. https://doi.org/10.1016/j.xrrt.2021.08.013

11. Ahmad C. How Tommy John surgery got its name may surprise you (2020, August 18th). Available from: https://www.drahmadsportsmedicine.com/tommy-john-surgery-got-name-may-surprise/ (accessed on 29 July 2025).

12. Jensen AR, LaPrade MD, Turner TW, Dines JS, & Camp CL. The History and Evolution of Elbow Medial Ulnar Collateral Ligament Reconstruction: from Tommy John to 2020. *Current reviews in musculoskeletal medicine*. 2020; 13 (3): 349–360. https://doi.org/10.1007/s12178-020-09618-y

13. Ulnar collateral ligament injury (Tommy John surgery/ UCL Repair). The Oklahoma Throwing Athlete Association: Sports Medicine Experts. Available from: https://www.okthrowingathlete.com/ulnar-collateral-ligament-injury-tommy-john-surgery-ucl-repair/ (accessed on 30 July 2025).

14. Torres SJ & Limpisvasti O. Ulnar Collateral Ligament Repair of the Elbow-Biomechanics, Indications, and Outcomes. *Current reviews in musculoskeletal medicine*. 2021; 14 (2): 168–173. https://doi.org/10.1007/s12178-021-09698-4

15. Patrick R, McGinty J, Lucado A & Collier B. CHRONIC UCL INJURY: A MULTIMODAL APPROACH TO CORRECTING ALTERED MECHANICS AND IMPROVING HEALING IN A COLLEGE ATHLETE- A CASE REPORT. International journal of sports physical therapy. 2016; 11 (4): 614–626.

16. Langer P, Fadale P & Hulstyn M. Evolution of the treatment options of ulnar collateral ligament injuries of the elbow. British journal of sports medicine. 2006; 40 (6): 499–506. https://doi.org/10.1136/bjsm.2005.025072

17. Triplet JJ, Labott JR, Leland DP, Cheema A, *et al*. Factors that Increase Elbow Stress in the Throwing Athlete: a Systematic Review of Biomechanical and Motion Analysis Studies of Baseball Pitching and Throwing. *Current reviews in musculoskeletal medicine*. 2023; 16 (4): 115–122. https://doi.org/10.1007/s12178-022-09800-4

18. Reiman MP, Walker MD, Peters S, Kilborn E, *et al*. Risk factors for ulnar collateral ligament injury in professional and amateur baseball players: a systematic

review with meta-analysis. *Journal of Shoulder and Elbow Surgery*. 2019; 28 (1): 186-195. https://doi.org/10.1016/j.jse.2018.08.018

19. Hibberd EE, Brown JR & Hoffer JT. Optimal management of ulnar collateral ligament injury in baseball pitchers. Open access journal of sports medicine. 2015; 6: 343–352. https://doi.org/10.2147/OAJSM.S71326

20. Van Trigt B, Vliegen LW, Leenen TA & Veeger DH. The ulnar collateral ligament loading paradox between in-vitro and in-vivo studies on baseball pitching (narrative review). *International biomechanics*. 2021; 8 (1): 19–29. https://doi.org/10.1080/23335432.2021.1916405

21. Smith C, Dowling B, Williams E, Magrini M, *et al*. Influence of Throwing Kinematics on Ulnar Collateral Ligament Thickness in Collegiate Baseball Players. Orthopaedic journal of sports medicine. 2025; 13 (4): 23259671251326030. https://doi.org/10.1177/23259671251326030

22. Chalmers PN, Erickson BJ, Ball B, Romeo AA & Verma NN. Fastball pitch velocity helps predict ulnar collateral ligament reconstruction in Major League Baseball pitchers. *The American journal of sports medicine*. 2016; 44 (8): 2130-2135. https://doi.org/10.1177/0363546516634305

23. Mastroianni MA, Kunes JA, Mueller JD, Obana KK, *et al*. Pitch-Specific Advanced Analytic and Pitch-Tracking Risk Factors for Ulnar Collateral Ligament Injuries in Major League Baseball Pitchers. *The American journal of sports medicine*. 2025; 53 (6): 1440–1449. https://doi.org/10.1177/03635465251330564

24. Fleisig GS, Slowik JS, Wychgram C, D'Angelo J, *et al*. Risk Factors for an Ulnar Collateral Ligament Injury Resulting in Surgery: A Prospective Longitudinal Study of 305 Professional Baseball Pitchers. *Orthopaedic journal of sports medicine*. 2025; 13 (7): 23259671251351339. https://doi.org/10.1177/23259671251351339

25. Freehill M, Dopkowski E, Workman W, Frangiamore S, *et al*. Poster 381: Biomechanical Risk Factors for Ulnar Collateral Ligament Injury and the Ability to Readily Recognize Them. Orthopaedic Journal of Sports Medicine. 2024; 12 (7 suppl2): 2325967124S00346. https://doi.org/10.1177/2325967124S00346

26. Confino J, Irvine JN, O'Connor M, Ahmad CS & Lynch TS. Early Sports Specialization Is Associated With Upper Extremity Injuries in Throwers and Fewer Games Played in Major League Baseball. *Orthopaedic journal of sports medicine*. 2019; 7 (7): 2325967119861101. https://doi.org/10.1177/2325967119861101

27. Ahmad C. Modifiable vs. non-modifiable risk factors for UCL injuries. Christopher Ahmad, MD. (2024, December 5) available from: https://drchrisahmad.medium.com/modifiable-vs-non-modifiable-risk-factors-for-ucl-injuries-201 ffcbe89ea (accessed on 2 August 2025)

28. Aibinder W & Throckmorton T. Ulnar collateral ligament (UCL) injury. American Academy of Orthopaedic Surgeons. 2024. Available from: https://orthoinfo.aaos.org/en/diseases–conditions/ulnar-collateral-ligament-ucl-injury/ (accessed on 3 August 2025)

29. Camp CL, Dines JS, Voleti PB, James EW & Altchek DW. Ulnar collateral ligament reconstruction of the elbow: the docking technique. *Arthroscopy Techniques*. 2016; 5 (3): e519-e523. https://doi.org/10.1016/j.eats.2016.02.013

30. Karbach LE & Elfar J. Elbow Instability: Anatomy, Biomechanics, Diagnostic Maneuvers, and Testing. *The Journal of hand surgery*. 2017; 42 (2): 118–126. https://doi.org/10.1016/j.jhsa.2016.11.025

31. Physiopedia Contributors. Elbow Valgus Stress. (2024, April 26). Physiopedia, . Retrieved 04:58, July 31, 2025 from https://www.physio-pedia.com/index.php?title=Elbow_Valgus_Stress&oldid=353659.

32. Physiopedia Contributors. Moving Valgus Stress Test. (2025, February 4). Physiopedia, . Retrieved 05:04, July 31, 2025 from https://www.physio-pedia.com/index.php?title=Moving_Valgus_Stress_Test&oldid=365726.

33. Orthofixar. Moving valgus stress test: Orthofixar 2025. OrthoFixar Orthopedic Surgery. (2025, February 20). Available from: https://orthofixar.com/special-test/moving-valgus-stress-test/ (accessed on 31 July 2025)

34. Physiopedia Contributors. Milking Maneuver. (2022, June 20). Physiopedia, . Retrieved 05:12, July 31, 2025 from https://www.physio-pedia.com/index.php?title=Milking_Maneuver&oldid=309551

35. Hariri S & Safran MR. Ulnar collateral ligament injury in the overhead athlete. Clinics in sports medicine. 2010; 29 (4): 619–644. https://doi.org/10.1016/j.csm.2010.06.007

36. Camp CL, Smith J & O'Driscoll SW. Posterolateral Rotatory Instability of the Elbow: Part II. Supplementary Examination and Dynamic Imaging Techniques. *Arthroscopy techniques*. 2017; 6 (2): e407–e411. https://doi.org/10.1016/j.eats.2016.10.012

37. Fedorka CJ & Oh LS. Posterolateral rotatory instability of the elbow. *Current reviews in musculoskeletal medicine*. 2016; 9 (2): 240–246. https://doi.org/10.1007/s12178-016-9345-8

38. Powell GM, Murthy NS & Johnson AC. Radiographic and MRI Assessment of the Thrower's Elbow. *Current reviews in musculoskeletal medicine*. 2021; 14 (3): 214–

223. https://doi.org/10.1007/s12178-021-09702-x

39. Hoshika S, Matsuki K, Izumi T, Takeuchi Y, Takahashi N & Sugaya H. Validation study of novel grading system for ulnar collateral ligament injury of the elbow with high-resolution magnetic resonance imaging. *JSES international.* 2021; 5 (5): 936–941. https://doi.org/10.1016/j.jseint.2021.05.011

40. LiMarzi GM, O'Dell MC, Scherer K, Pettis C, Wasyliw CW & Bancroft LW.Magnetic resonance arthrography of the wrist and elbow. *Magnetic Resonance Imaging Clinics.* 2015; 23 (3): 441-455. https://doi.org/10.1016/j.mric.2015.04.003

41. 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): 297–299. https://doi.org/10.1148/radiology.197.1.7568841

42. Manske RC, Voight M, Wolfe C & Page P. The Use of MSK Ultrasound in the Evaluation of Elbow Ulnar Collateral Ligament Injuries. *International journal of sports physical therapy.* 2023; 18 (2): 74018. https://doi.org/10.26603/001c.74018

43. Rubin G. Stress Ultrasound of the UCL. Sports Medicine Review. 2025, June 6. Available from: https://www.sportsmedreview.com/blog/dynamic-ucl-stress-test/ (accessed on 30 July 2025)

44. Park JY, Kim H, Lee JH, Heo T, *et al*. Valgus stress ultrasound for medial ulnar collateral ligament injuries in athletes: is ultrasound alone enough for diagnosis?. *Journal of shoulder and elbow surgery.* 2020; 29 (3): 578-586. https://doi.org/10.1016/j.jse.2019.12.005

45. Dahhan H, Knipe H, Ulnar collateral ligament reconstruction. Reference article, Radiopaedia.org available from: https://doi.org/10.53347/rID-211168 (Accessed on 07 Aug 2025)

46. Wear SA, Thornton DD, Schwartz ML, Weissmann III, RC, *et al*. MRI of the reconstructed ulnar collateral ligament. *American Journal of Roentgenology.* 2011; 197 (5): 1198-1204. https://doi.org/10.2214/AJR.11.6461

47. Hones KM, Simcox T, Hao KA, Portnoff B, *et al*. Graft choice and techniques used in elbow ulnar collateral ligament reconstruction over the last 20 years: a systematic review and meta-analysis. *Journal of shoulder and elbow surgery.* 2024; 33 (5): 1185–1199. https://doi.org/10.1016/j.jse.2023.10.023

48. Smith MV. Ulnar collateral ligament reconstruction with allograft: is it a home run?. The Journal of bone and joint surgery. *American volume.* 2013; 95 (12): e87. https://doi.org/10.2106/JBJS.M.00524

49. Kennon JC, Marigi EM, Songy CE, Bernard C, *et al*. Is Allograft Reconstruction of the Medial Ulnar Collateral Ligament of the Elbow a Viable Option for Nonelite Athletes? Outcomes at a Mean of 8 Years.

Orthopaedic journal of sports medicine. 2020; 8 (10): 2325967120959141. https://doi.org/10.1177/2325967120959141

50. Trofa DP, Constant M, Crutchfield CR, Dantzker NJ, *et al*. Return-to-Sport Outcomes After Primary Ulnar Collateral Ligament Reconstruction With Palmaris Versus Hamstring Tendon Grafts: A Systematic Review. *Orthopaedic journal of sports medicine.* 2021; 9 (12): 23259671211055726. https://doi.org/10.1177/23259671211055726

51. ÇETİN Dr. Dt. E. (2024, August 10). Autograft tissue: Definition, how it works, purpose, procedure, advantages/. Myra Dental Centre Turkey. Available from: https://www.myradental.co.uk/autograft-issue-definition-how-it-works-purpose-procedure-advantages/ (accessed on 3 August 2025)

52. Izzo CM. Choosing an allograft or autograft in orthopedic surgeries for athletes. University of New Hampshire Scholars' Repository. 2016. https://scholars.unh.edu/cgi/viewcontent.cgi?article=1307&context=honors

53. What is allograft tissue and is it safe?. UnderstandOrtho. (2023, May 31). Available from: https://www.understandortho.com/article/what-is-allograft-tissue-and-is-it-safe/ (accessed on 4 August 2025)

54. Moore A, Matthews D, Stausmire J, Singleton A, Davis K & Gupta A. Ulnar collateral ligament reconstruction: Allograft versus autograft – a systematic review. Orthopedic Research Online Journal. 2021; 8 (4). https://doi.org/10.31031/oproj.2021.08.000694

55. Anderson FL, Heffernan JT & Ahmad CS. UCL reconstruction in the throwing elbow. *Operative Techniques in Sports Medicine.* 2020; 28 (2): 150736. https://doi.org/10.1016/j.otsm.2020.150736

56. Molenaars RJ, Hilgersom NFJ, Doornberg JN, van den Bekerom MPJ & Eygendaal D. Review of Jobe *et al*. (1986) on reconstruction of the ulnar collateral ligament in athletes. *Journal of ISAKOS.* 2018; 3 (1): 55–62. https://doi.org/10.1136/jisakos-2017-000134

57. Cain EL, Andrews JR, Dugas JR, Wilk KE, *et al*. Outcome of ulnar collateral ligament reconstruction of the elbow in 1281 athletes: Results in 743 athletes with minimum 2-year follow-up. *The American Journal of Sports Medicine.* 2010; 38 (12): 2426–2434. https://doi.org/10.1177/0363546510378100

58. Erickson BJ, Gupta AK, Harris JD, Bush-Joseph CA, *et al*. Rate of return to pitching and performance after Tommy John surgery in Major League Baseball pitchers. *The American Journal of Sports Medicine.* 2014; 42 (3): 536–543. https://doi.org/10.1177/0363546513510890

59. Jensen AR, LaPrade MD, Turner TW, Dines JS

& Camp CL. The History and Evolution of Elbow Medial Ulnar Collateral Ligament Reconstruction: from Tommy John to 2020. *Current reviews in musculoskeletal medicine.* 2020; 13 (3): 349–360. https://doi.org/10.1007/s12178-020-09618-y

60. Camp CL, Bernard C, Dines JS, Altchek DW & Dines DM. A prospective, randomized trial of the modified Jobe versus docking techniques with gracilis autograft for ulnar collateral ligament reconstruction in the elbow. *Sports Medicine - Open.* 2018; 4 (1): 25. https://doi.org/10.1016/j.eats.2016.01.019

61. Christopher Camp, Christopher Bernard, Bill Benavitz, John Konicek, David Altchek & Joshua Dines. Reconstruction of the Medial Ulnar Collateral Ligament of the Elbow: Biomechanical Comparison of a Novel Anatomic Technique to the Docking Technique. *Orthopaedic Journal of Sports Medicine.* 2019; 7: 232596711985759. 10.1177/2325967119857592.

62. Ahmad CS, Lee TQ & ElAttrache NS. Biomechanical evaluation of a new ulnar collateral ligament reconstruction technique with interference screw fixation. *The American Journal of Sports Medicine.* 2003; 31 (2): 332–337. https://doi.org/10.1177/03635465030310030201

63. Ahmad CS & ElAttrache NS. Elbow valgus instability in the throwing athlete. *Journal of the American Academy of Orthopaedic Surgeons.* 2006; 14 (11): 693–700. https://doi.org/10.5435/00124635-200611000-00014

64. Wilk KE, Thomas ZM, Arrigo CA, Campbell AM, *et al.* The use of the internal brace to repair the UCL injury of the elbow in athletes. *International Journal of Sports Physical Therapy.* 2022; 17 (7): 1208–1218. https://doi.org/10.26603/001c.39614

65. Arthrex. (n.d.). InternalBrace™ ligament augmentation repair. Retrieved from Arthrex website (discusses the internal brace principle and fixation method) available from: https://www.arthrex.com/elbow/ucl-internalbrace-ligament-augmentation-repair?currenttab=resources (accessed on 23 July 2025)

66. Roth TS, Beason DP, Clay TB, Cain EL, Jr. & Dugas JR. The effect of ulnar collateral ligament repair with internal brace augmentation on articular contact mechanics: A cadaveric study. Orthopaedic

Journal of Sports Medicine. 2021; 9 (4): Article 23259671211001069. https://doi.org/10.1177/23259671211001069

67. Wilk KE, Arrigo CA & Andrews JR. Rehabilitation following elbow ulnar collateral ligament injury and surgery. *International Journal of Sports Physical Therapy.* 2022; 17 (4): 758–772.

68. Ra'kerry Rahman, William Levine & Christopher Ahmad. Elbow medial collateral ligament injuries. Current reviews in musculoskeletal medicine. 2009; 1: 197-204. 10.1007/s12178-008-9026-3.

69. Craig Melbourne, James Cook, Gregory Rocca, Christopher Loftis, John Konicek & Matthew Smith. Biomechanical assessment of lateral ulnar collateral ligament repair and reconstruction with or without internal brace augmentation. *JSES International.* 2020; 4. 10.1016/j.jseint.2020.01.011.

70. Podesta L, Crow SA, Volkmer D, Bert T & Yocum L. Treatment of partial ulnar collateral ligament tears in the elbow with PRP. *American Journal of Sports Medicine.* 2013; 41 (7): 1689–1694. https://doi.org/10.1177/0363546513487979

71. Langhans MT, Boos AM, Iyer S, Simon KN, *et al.* Current State of Baseball Interval Throwing Programs: A Systematic Review of Content, Structure, and Variability of Published Throwing Programs. Sports health. 2025; 19417381251333402. Advance online publication. https://doi.org/10.1177/19417381251333402

72. Lin KM, Ellenbecker TS & Safran MR. Rehabilitation and Return to Sport Following Elbow Injuries. Arthroscopy, sports medicine, and rehabilitation. 2022; 4 (3): e1245–e1251. https://doi.org/10.1016/j.asmr.2022.01.012

73. Beaudry MF, Beaudry AG, Bennett MM, Gilliam BD, *et al.* Sex-specific differences in elbow ulnar collateral ligament injuries: A retrospective analysis. *Journal of Women's Sports Medicine.* 2023; 3 (1). https://doi.org/10.53646/jwsm.v3i1.33

74. Gerard III, NO, Clark SC, O'Brien MJ, Mulcahey MK & Savoie FH. Operative treatment of ulnar collateral ligament injury in female athletes. *Orthopaedic Journal of Sports Medicine.* 2024; 12 (3): 23259671241235600. https://doi.org/10.1177/23259671241235600