An Overview of Ulnar Collateral Ligament Tears in Baseball Players

Gabe Dimock

Introduction

In recent years, the incidence and prevalence of elbow ulnar collateral ligament (UCL) tears in baseball players has increased at multiple levels of play.[1] Between 2007 and 2011, the incidence of UCL tears increased by more than 9% in players between the ages of 15 and 19.[1] From 2012 to 2018, the prevalence of UCL reconstruction increased from 10% to 13% in professional baseball players with an increase from 16% to 20% when only considering pitchers.[2] Conte et al. analyzed injury trends in major league baseball from 1998-2015 using data from the disabled list and found that the annual incidence of UCL reconstructive surgeries has significantly increased from year to year.[3] The authors found that 32.8% of the UCL reconstructive surgeries over the 42-years since its inception occurred from 2011-2015 (Figure 1).[3] While the literature suggests that the rate of return to play following UCL reconstruction is fairly high, there is a prolonged absence from competition and no guarantee that the patient will regain full function.[4] Given the concerning increase in injury incidence and the significant impact that UCL injury can have on the levels of activity and participation of baseball players at any level, clinicians need to understand the variables that play a role in UCL injury and recovery. This paper aims to provide an overview of the structure and function of the UCL, the common mechanisms of injury, UCL injury prevention, the means of diagnosis, and surgical and conservative management of UCL injuries.

Structure, Function, and Blood Supply of the UCL

Capsular, ligamentous, and muscular soft tissues provide stability to the elbow when the elbow is flexed between 20 and 120 degrees, while the bony anatomy is primarily responsible for the stability at extremes of elbow flexion and extension.[5] During the thrower's arc of motion, the elbow is typically flexed between 20 and 120 degrees which increases the stabilizing demand of the soft tissues.[5] The primary role of the UCL in the elbow is to resist valgus force which results in medial tensile stress and lateral compressive stress.[5] Within the UCL are three bundles, the anterior oblique ligament (AOL), the posterior oblique ligament (POL), and the transverse ligament (TL) (Figure 2).[5] The AOL spans from the medial epicondyle of the distal humerus to the medial aspect of the proximal ulna and is the primary restraint to valgus force when the elbow is flexed between 30 and 120 degrees.[5] Compared to the other two bundles of the UCL, the AOL can resist the most force at approximately 260 N.[5] The POL has a similar location and function to the AOL as the POL is a secondary valgus restraint and runs from the distal humerus to the proximal, medial ulna but has a more posterior origin compared to the AOL and is more fan-like.[5] The final component of the UCL is the TL which does not provide stability to the elbow and runs from the AOL and POL insertions on the ulna.[5] Perhaps the reason that the AOL is a primary restraint that can withstand greater force is that it has anterior, posterior, and central bands that serve to provide support to the elbow joint.[5] The anterior band of the AOL becomes taut up to 90 degrees of elbow flexion at which point the posterior band becomes taut until 120 degrees of elbow flexion is achieved.[5] The throwing motion consists of the following six phases: windup, early cocking/stride, late cocking, acceleration, deceleration, and follow-through.[6] Valgus stresses are greatest during the late cocking and acceleration portions of the throwing motion when the shoulder is in external rotation, the elbow is flexed, and the ball/hand/forearm complex is creating a valgus moment about the elbow (figures 3 and 4).[5] The UCL stabilizes the elbow by producing internal varus torque to counter the external valgus moment while also resisting elbow extension during the deceleration phase of throwing.[1] When an injury to the UCL occurs, it is important to consider the blood supply to the tissue as this has implications for healing capacity and intervention choice. A 2019 study by Buckley et al. examined the UCL of 9 cadavers and found that the proximal aspect of the ligament had a rich vascular supply while the distal ligament had poor blood supply.[7] Based on this evidence, the choice of surgical vs conservative intervention may be influenced by the location of the injury.[7]

UCL Mechanism of Injury and Risk Factors

Elbow UCL injuries in throwers are predominately thought to be due to chronic microtrauma to the connective tissue from repetitive throwing given that pitchers typically throw thousands of pitches per season.[8,9] However, even a single throw places a great deal of stress on the body as the stress may be greater than five times the thrower's body weight and occur at high speeds of 7000 degrees per second.[8] Additional biomechanical laboratory studies have shown that the magnitude of the valgus forces during the late cocking and acceleration phases of throwing can reach approximately 64 N m which exceeds the maximum force of 33 N m of valgus force withstood in cadaver studies.[5] This indicates that other bony and soft tissue forces allow for greater stability so that a single throw does not generally result in an injury to the elbow UCL.[5] Whiteside et al. conducted a 2016 case-control study that used data from professional pitchers who underwent UCL reconstruction to matched uninjured controls to identify predictors of UCL injury.[9] The findings of this study support the hypothesis that increased stress to the elbow in the form of increased throwing volume and velocity was correlated to increased injury risk.[9] Based on the odds ratio found by the authors, each 1-pitch increase in average number of pitches thrown per game increased relative risk of undergoing UCL surgery by 2%.[9] However, the study does not account for variables such as the number of practice pitches thrown per season, the volume of throwing undertaken by the pitcher in the offseason, or the volume of throwing that has accumulated over their playing career. The trend of increased early sport specialization may be a primary factor that is driving up the accumulated volume of throwing as recent evidence by Confino et al. has shown that 60% of high school athletes are specializing in baseball compared to 45% a decade ago.[10] Additionally, this specialization appears to be taking place at younger ages as the average found by Confino et al., was 12.3 years of age compared to 15.4.[10] Early sport specialization in baseball is often seen due to the theory that this will result in greater skill and performance.[10] Ironically, Confino et al. found that those who were multi-sport athletes were no less likely to play in the major leagues and that they were significantly less likely to incur injuries.[10] Those who were multi-sport athletes were found to play significantly more MLB games during their careers.[10] An increase in throwing velocity is often sought after by players and coaches due to its ability to increase a pitcher's effectiveness although it increases valgus stress on the elbow. Whiteside et al. found that a 1 m/s (2.24 mph) increase in throwing velocity resulted in a 38% increase in relative risk of UCL injury.[9] Some of the recent popular means of increasing throwing velocity have included long-toss programs that are often conducted in the off-season and the use of weighted balls that are heavier and lighter than the traditional 5 oz. baseball.[11,12] A biomechanical analysis by Flesig et al. of players performing long-toss throws compared to more game-like, flat throws, showed that the maximum distance throws produced greater elbow torque without an increase in ball velocity which indicates that this is an inefficient type of throw.[11] Additionally, there were problematic changes in throwing mechanics that accompanied the maximum distance throws including increased transverse plane rotation compared to sagittal plane rotation which will be discussed in greater detail below.[11] The use of balls heavier and lighter than the standard 5 oz. baseball incorporates the principle of overload/underload training that is commonly used in strength training to improve pitching velocity.[13] While DeRenne et al. found that this intervention did significantly increase pitch velocity in a 10-week program, Okoroha et al. found that the medial elbow torque increased with increased ball weight.[12,13] The increased volume both during the competitive season and in the off-season of throwing in combination with a pursuit of increased velocity through means that place greater valgus stress on the UCL is a common scenario that has likely played a significant role in the increased injury rate observed in recent decades. Other factors that were identified by Whiteside et al. to be risk factors for UCL injury were decreased rest between throwing bouts and a smaller number of different pitch types thrown.[9] It was observed that uninjured controls had 12-19% more rest in-between pitching bouts compared to those who had a UCL injury.[9] In contrast to popular belief, the fastball has been shown to place more stress on the elbow than other pitch types including the often blamed curveball.[9] It may be that there is a decrease in injury rate associated with an increased repertoire of pitches due to a decreased percentage of fastballs thrown.

Skeletal alignment and range of motion differences between the dominant and non-dominant upper extremities have been discussed as possible risk factors in the literature. A study by Noonan et al. utilized a case-control study design using 255 pitchers from the Colorado Rockies organization and found that pitchers that had an elbow injury had greater humeral retrotorsion while those with shoulder injuries had less humeral retrotorsion.[14] This indicates that the adaptive skeletal change to repetitive throwing that occurs during development may be protective against shoulder injuries but place the elbow at greater risk for injury.[14] While the mechanism behind this association is not definite, it has been hypothesized that the increase in humeral retrotorsion allows for greater external rotation which prolongs the late-cocking and early acceleration phases of throwing where the UCL is under the most tensile stress (Figures 3 and 4).[14] Along the same logic, those who have greater humeral retrotorsion are likely to demonstrate greater glenohumeral internal rotation deficit compared to the non-dominant side which has been associated with an increased risk of UCL injury.[14]

Throwing mechanics should not be overlooked when discussing risk factors for injury to the UCL as the evidence supports that more efficient throwing mechanics can decrease the valgus stress placed on the UCL. Camp et al. evaluated analyzed elbow valgus torque captured using a Motus arm sleeve during 82,000 throws of a variety of throw type from 81 professional baseball players.[15] The data showed that arm slot, arm speed, and maximal external rotation were all significantly correlated to elbow torque.[15] While arm speed and maximal external rotation are unlikely to be modified due to the performance benefits to be gained from greater throwing velocity, the arm slot may be changed without definite performance decrements. It was found that there was a 1 N m increase in elbow torque observed with a 13-degree decrease in arm slot.[15] Portney et al. utilized MLB pitch tracking data to find out whether the release point during the previous year was associated with UCL reconstruction.[16] The data showed that the players who required UCL reconstruction began with a similar release point to the uninjured control group but that as they approached the time of injury, the release point trended more laterally as demonstrated by a release point that was 12.2 cm more lateral than the control group.[16] In 2018, Orenduff et al. presented the Delivery Value System (DVS) which is a statistical model for assessing a pitcher's injury risk that is based on the following 6 tenets of throwing mechanics: mass and momentum, arm swing, posture, position at foot strike, path of arm acceleration, and finish.[17] The DVS was validated using a random video sample of 449 professional pitchers as the risk of injury was significantly reduced with increases in the overall DVS score (7.8%) and increases in the mass and momentum (16.5%), position at foot strike (22.8), and arm swing scores (12.0%).[17] The mass and momentum score refers to the extent to which the lower extremities and trunk work in conjunction with the arm to deliver the pitch.[17] Increased use of the lower extremities and trunk allows for a more efficient delivery and similar velocity production with decreased relative stress to the elbow. The position at foot strike (Figures 5 and 6) was found to be the individual component of the DVS that was the most powerful predictor of injury.[17] This position refers to the position of the trunk and throwing arm when the lead foot is planted in the ground.[17] The ideal position at this stage of the pitching delivery includes hips that have opened towards the target, a trunk that remains closed, and a throwing forearm that is vertical in space.[17] This allows the arm to enter the late-cocking phase of throwing in closer connection with the torso and a moment arm that is shorter relative to the axis of rotation of the trunk and shoulder. The combination of using the mass and momentum of the lower extremity and trunk with attaining an ideal position at foot strike allows for efficiency of the pitching delivery that may decrease relative stress to the throwing elbow while maintaining performance markers of velocity and control.[17] As demonstrated by the plethora of risk factors for UCL injury discussed above, injury prevention is no easy task. However, knowledge of the risk factors may allow players, coaches, clinicians, and parents to team up to address the modifiable risk factors to limit exposure when possible.

Injury Prevention

Much of the specific evidence in the literature regarding UCL injury prevention for baseball players is in the form of expert opinion based on many of the risk factors discussed above.[1] At the forefront of injury prevention initiatives are attempts to limit pitching volumes and increase the amount of rest through the use of safety rules.[1] These are usually implemented at lower levels of play and typically consist of pitch number limits and a minimum mandatory rest period that is determined by the number of pitches thrown and the age of the player. The most widely used pitching safety rules are the Pitch Smart guidelines that were developed by the MLB and USA Baseball through expert consultants.[18] The Pitch Smart guidelines can be seen in table 1 below.[19] While these guidelines may be a good start, longitudinal data should be collected to determine the effectiveness and the compliance with these guidelines. Significant challenges to pitch count and rest guidelines are players who play on multiple teams during the same season as well as the lack of accounting for practice throws and throws performed while playing positions other than pitcher. Another preventative measure to be taken is the discouragement of early sport specialization and year-round play. A study by Pytiak et al. utilized MRI imaging of the elbows of 26 little leaguers before the season and after the season.[20] MRI abnormality was found in 12 of the 26 players in the study with year-round play (>8 months) being the only variable that was significantly associated with MRI abnormality.[20] Additionally, playing greater than 8 months per year has been shown to increase throwing injury risk five-fold.[1] Injury prevention programs for throwers also commonly address strength and mobility deficits in the shoulder, lower extremities, and trunk as impairments in these areas may contribute to increased stress being placed on the elbow which increases the probability of UCL failure.[1] Preseason programs are also recommended gradually increases in intensity, frequency, and duration to condition the tissues including the UCL to withstand the demands of a long baseball season.[1] However, no definitive program has been developed that is safe and effective for minimizing elbow injury risk. Additionally, many of these throwing problems sell velocity rather than safety and include long-toss and/or weighted balls which may overload the UCL as mentioned above.[11,12] Future research in this area may be beneficial in determining the optimal parameters of a preseason throwing program. Addressing inefficiencies in throwing mechanics may provide a protective benefit while maintaining or enhancing performance. Improving the use of mass and momentum, obtaining a closed torso at foot strike with a forearm on the vertical in space, and a more overhead arm slot can result in decreased stress to the UCL.[17] The use of video analysis and/or a throwing coach who values injury prevention and is educated on the principles of efficient throwing may be beneficial in achieving the biomechanical changes presented above. Lastly, the use of an outcome measure that can identify throwers at higher risk for injury may be helpful in timely intervention that may prevent failure of the UCL. The Kerlan-Jobe Orthopaedic Shoulder and Elbow Score (KJOC) consists of 10 questions that patients answer on a scale of 1-10 with anchors at 1 and 10 given.[21] The KJOC is a sensitive measure for changes in upper extremity performance and is lower in individuals who have had a history of shoulder or elbow surgery.[22] While not yet validated for this purpose, future research may be conducted prospectively to determine whether the KJOC can detect future injury risk. If so, this may be a valuable tool for clinicians in making individualized injury prevention recommendations.

Clinical Indicators of UCL Insufficiency and Diagnosis

A systematic review by Zwerus et al. found that the moving valgus stress test, the valgus stress test, and the milking maneuver (Figures 7-9) are used clinically to detect UCL insufficiency but that only the moving valgus stress test and valgus stress test have reported psychometric properties.[23] In the moving valgus stress test, the clinician provides valgus stress to the elbow with the shoulder at 90 degrees of abduction, maximal external rotation, and the elbow maximally flexed.[23,24] The clinician maintains the valgus force while quickly extending the elbow to approximately 30 degrees.[24] A positive moving valgus stress test is indicated by a reproduction of pain between 120 degrees and 70 degrees of elbow flexion.[23] The moving valgus stress test has strong psychometric properties with a sensitivity of 75% and a specificity of 100%.[23] The traditional valgus stress test is a more simple version of the moving valgus stress test as the elbow is flexed to 70 degrees and valgus stress is imposed by the clinician.[23] A positive on this test may be pain or laxity but the psychometric properties vary depending on the use of pain or laxity as a positive indicator.[23] When pain is used as the indicator, the sensitivity for the valgus stress test is 65% while the specificity is 50%.[23] When instability is used as the indicator, the test has poor sensitivity but 100% specificity.[23] The milking maneuver has been described in the literature but has no reported psychometric properties.[23] When performing the milking maneuver, the forearm is in full supination with the elbow flexed beyond 90 degrees.[25] The thumb is pulled laterally to induce a valgus stress with pain, apprehension, and/or instability being the indicators for a positive test.[25] Definitive diagnosis of a UCL injury is determined by MRI and can be classified based on the location and severity of the tear (Table 2).[26] This classification can be used to make clinical decisions regarding surgical vs conservative intervention. In a retrospective analysis of 80 patients with a UCL tear, patients with more proximal and partial UCL tears were more likely to undergo conservative management compared to those with more distal, complete tears.[26] Based on the data, it appears that the location of the UCL tear was a more powerful indicator of the injury management decision compared to the severity of the tear.[26] This is logical based on the blood supply to the UCL being significantly greater proximally compared to distally which indicates a greater healing capacity of the proximal ligament.[7] In cases where conservative management is chosen, surgery may be reconsidered if the patient does not respond well to conservative treatment interventions.[1]

UCL Reconstruction Overview, Rehabilitation, and Outcomes

When surgical intervention is chosen, a graft from a donor site is used.[25] Autograft options include the tendons of the palmaris longus, gracilis, semitendinosus, toe extensor, or plantaris, tendon while an allograft UCL is also an option.[25] The palmaris longus is the most commonly used graft but the evidence does not seem to favor one graft type over another.[25] There are also many different surgical techniques used for a UCL reconstruction that primarily differ based on the management of the ulnar nerve, the graft configuration, and the technique used to attach the graft to the ulna and humerus.[25] Similar to the graft type chosen, no single technique is superior to the others.[25] The postoperative rehabilitation process typically consists of 4 progressive phases with the return to sport time fluctuating widely.[25] The estimated time from surgery to return to sport is 7-9 months but is often extended to 10-18 months.[25] The four-phase postoperative rehabilitation protocol presented by Erickson et al. is summarized in Table 3.[25] Research conducted to determine return to sport rates and performance changes after UCL reconstruction show mixed results with players returning to at least the same level of play 75-94% of the time.[1] Some studies found that player performance was decreased upon return to sport while other studies found improved performance.[1] However, no increase in throwing velocity is seen after UCL reconstruction which is typically the reason cited by uninjured players and/or parents who request the surgery.[1] Additionally, improvements after UCL reconstruction may be due to performance decrements that occurred before the ultimate failure of the UCL as it is likely that accumulated microtrauma to the UCL affected performance. UCL reconstruction should never be performed in the absence of an injury in an attempt to improve performance.[25]

Conservative Management Overview

Non-surgical treatment for a UCL injury is often the trialed in cases where healing is plausible to better determine whether the patient will require surgical intervention.[27] A typical four-phase conservative protocol described by Biz et al. is presented below in table 4.[27] In comparison of the post-operative protocol to the conservative protocol, the protocols have similar components but the post-operative protocol is more time-based while the conservative protocol relies more on patients reaching criteria to move to the next phase.[25,27] Additional conservative treatment options that have shown promising results in recent studies are platelet-rich plasma (PRP) injections and the use of a dynamic external fixator combined with therapy.[27]

Outcomes for patients who opt for conservative management are variable as one study showed that only 42% of patients were able to return to sport after 6 months of non-surgical treatment.[27] Given that many patients who choose conservative treatment will eventually require surgery, these patients may experience a prolonged overall return to sport time.

Conclusion

UCL injuries have become increasingly common in baseball players in recent years due to large volumes of throwing with insufficient rest, and an emphasis on velocity development which has led to early sport specialization and aggressive year-round throwing training that places increased stress on the UCL.[1,9–12] Additionally, players often demonstrate inefficient throwing mechanics that contribute to the chronic stress that eventually leads to injury.[16,17] A priority for clinicians who work with baseball players should be to intervene at the earliest signs of medial elbow pathology through education regarding the volume of throwing, rest recommendations, and throwing mechanics. While there are clinical tests used to detect a UCL injury, the injury is confirmed and classified using MRI imaging.[23,26] Once a UCL injury has been confirmed, a decision regarding treatment mode should be made in collaboration with the player, their parent (if applicable), and the MD. Treatment options include UCL reconstruction or conservative management.[25,27] Return to sport rates after surgical intervention ranged from 75-94% with a variable time to return that may occur anywhere from 7-18 months post-surgery.[1] Successful conservative treatment generally results in a return to sport in less than 6 months but evidence has shown that less than half (42%) of players choosing conservative treatment were successful.[25,27] Whether post-surgical or conservative, rehabilitation programs for patients with UCL injuries should include pain and inflammation reduction, restoration of elbow ROM, strength, and neuromuscular control as well as a progressive throwing program that allows for tissue adaptation that can withstand the heavy demands of repeated throwing.[25,27]

Figures and Tables:

Figure 1: UCL Reconstructions on MLB Players by Year[3]

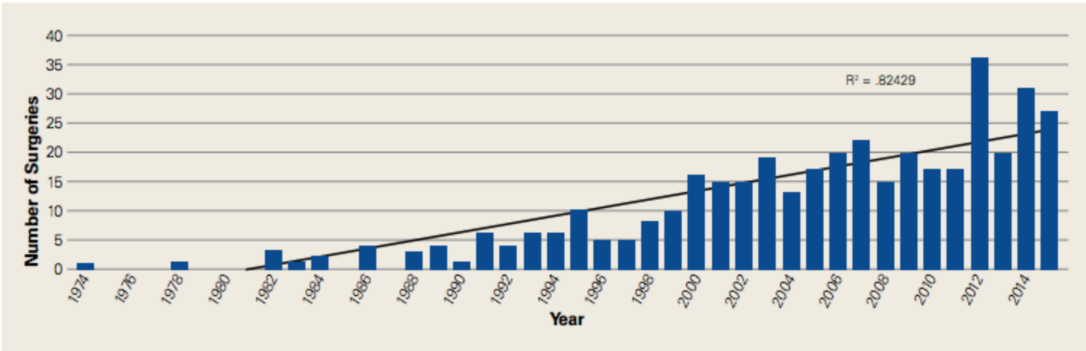

Figure 2: Anatomy of the UCL[28]

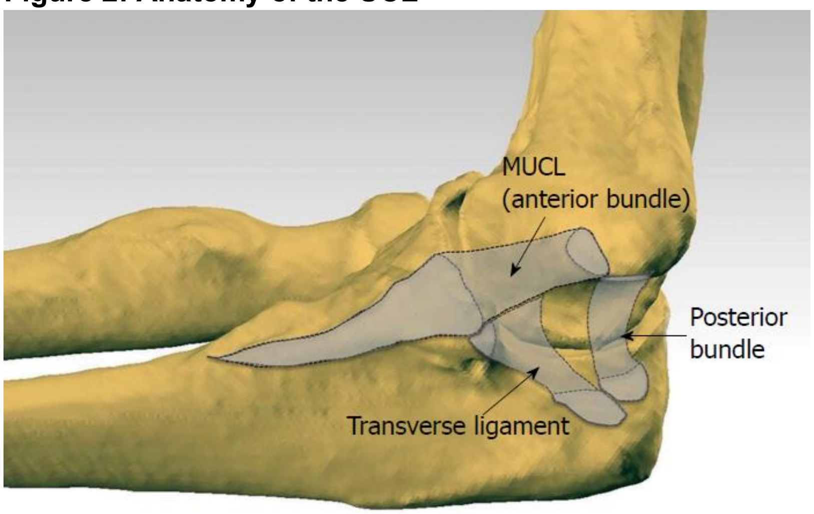

Figure 3: Late-Cocking Phase of Throwing[29]

Figure 4: Acceleration Phase of Throwing[29]

Figure 5: Position at Foot Strike (Back View)[30]

Figure 6: Position at Foot Strike (Side View)[31]

Figure 7: Moving Valgus Stress Test[25]

Figure 8: Valgus Stress Test[25]

Figure 9: Milking Maneuver[25]

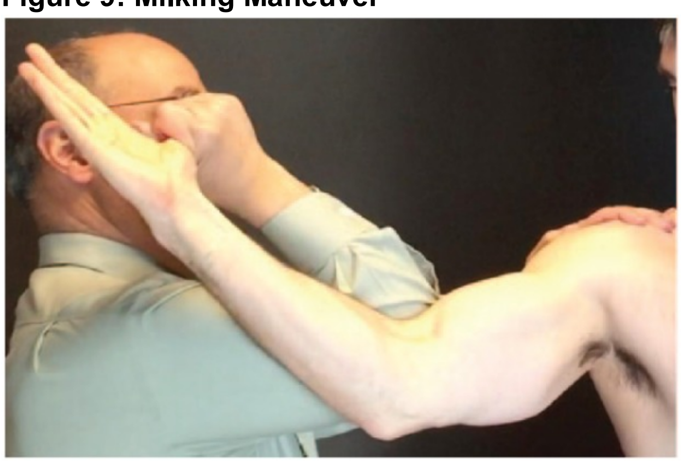

Table 1: Pitch Smart Guidelines[19]

Age	Daily Maximum for In-Game Pitches	0 Day Rest	1 Day Rest	2 Days Rest	3 Days Rest	4 Days Rest	5 Days Rest
7-8	50	1-20	21-35	36-50	N/A	N/A	N/A
9-10	75	1-20	21-35	36-50	51-65	66+	N/A
11-12	85	1-20	21-35	36-50	51-65	66+	N/A
13-14	95	1-20	21-35	36-50	51-65	66+	N/A
15-16	95	1-30	31-45	46-60	61-75	76+	N/A
17-18	105	1-30	31-45	46-60	61-80	81+	N/A
19-22	120	1-30	31-45	46-60	61-80	81-105	106+

Table 2: UCL Injury MRI Classification[26]

Stage	Description
1A	Partial tear of the proximal UCL
1B	Complete tear of the proximal UCL
2A	Partial tear of the mid-substance UCL
2B	Complete tear of the mid-substance UCL
3A	Partial tear of the distal UCL
3B	Complete tear of the distal UCL

Table 3: Post-Operative Rehabilitation Protocol Summary[25]

Phase	Aims	Interventions
Phase I (0-3 weeks)	Promote healing, prevent stiffness	Week 1: Immobilization Week 2: Gentle ROM in a hinged elbow brace from 30-100 degrees of flexion Week 3: Gentle ROM in a hinged elbow brace from 15-110 degrees of flexion
Phase II (4-8 weeks)	Restore strength, continue ROM improvement	Increase ROM by 5 degrees each week until full ROM is restored. Begin elbow, shoulder, and scapular strength exercises with 1 lb. weights and increase by 1 lb. each week.
Phase III (9-13 weeks)	Restore neuromuscular function, improve strength and flexibility, begin sport-specific plyometric program	Isotonic and manual resistance exercises, proprioception and dynamic stabilization exercises, proper throwing mechanics

		emphasized upon beginning of sport-specific program
Phase IV (14-26 weeks)	Improve throwing ability and tolerance	Begin throwing program that begins with 45-foot throws that gradually progresses to 120 feet. After this is accomplished, throwing from a mound or other game-like throws are introduced at progressive intensity, frequency, and duration.

Table 4: Non-Surgical Rehabilitation Protocol[27]

Phase	Aims	Interventions
Phase I (0-3 weeks)	Decrease pain and inflammation, minimize additional valgus stress, minimize strength loss, controlled ROM	ROM between 30-110 degrees with brace, ice and anti-inflammatory medication, light isometric strengthening
Phase II (4-5 weeks)	Regain full, pain-free ROM, minimize valgus loading, improve neuromuscular control	Increase ROM by 5-10 degrees per week, stretching, isotonic strengthening, dynamic stabilization and proprioception exercises
Phase III (6 weeks-full ROM, strength, stability)	Increase strength and stability of the elbow	Progressive loading of the elbow, plyometric exercises
Phase IV (Begins when full ROM, strength, and stability is restored)	Return to sport-specific activity	Progressive increase in throwing intensity, frequency, and duration

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