Elbow Ulnar Collateral Ligament: Injury, Treatment Options, and Recovery in Overhead Throwing Athletes

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Abstract
The ulnar collateral ligament (UCL) of the elbow has been a subject of extensive research and discussion in recent years not only in the medical community but also in the media and by coaches, players, and parents. This is in part due to the rising incidence of UCL injuries and subsequent surgical reconstruction, specifically in overhead throwing athletes. Due to this widespread increase in injury to this structure, it is paramount to understand when it is appropriate to pursue nonoperative versus operative management. As such, the purpose of this article will be to review the basic anatomy, risk factors for UCL injury in overhead throwing athletes, treatment approaches, and future directions for prevention and treatment of injury based on the evidence-based data in the peer-reviewed literature.

Introduction
In the past two decades, the incidence of elbow ulnar collateral ligament (UCL) injury and rupture in overhead throwers at all levels of baseball play has increased considerably (1–3). Unfortunately, projections estimate that the incidence of these injuries will likely contribute to more UCL-reconstruction procedures (UCL-R or “Tommy John Surgery”) through at least 2025. The number of UCL injuries and its associated impact on participation in throwing sports reinforces the importance of disseminating accurate evidence-based information in a medical journal to all medical professionals involved in the care of these athletes.

UCL Anatomy, Function, and Injury Mechanism
The UCL of the elbow is composed of three bundles (Fig. 1). The anterior oblique ligament (AOL) or bundle, posterior oblique ligament (POL) or bundle, and the transverse ligament (which unites the AOL and POL). The AOL is the strongest elbow collateral ligament with an average failure load of 260 N (4). The osseous origin is the anterior-inferior aspect of the medial epicondyle of the humerus while the insertion is the proximal aspect of the ulna known as the sublime tubercle. The function of the UCL includes elbow joint stability and resistor of valgus loads. Of the three ligaments making up the UCL complex, only the AOL provides significant restraint to valgus force of the elbow from 30° to 120° of flexion, which is an important factor to consider when evaluating and treating overhead athletes (5). The UCL provides elbow joint stability by slowing elbow extension during the deceleration phase of throwing and generates a varus torque counterbalancing the pitch mechanic induced valgus force. During overhead throwing, a large valgus moment (as high as 64 N·m⁻¹) on the elbow is generated (6). However, the known tensile strength of the UCL is only 33 N·m⁻¹ based on cadaveric research (7). Thus, repetitive, near-failure tensile stress with poor stabilization from surrounding musculature, such as the flexor-pronator muscles, can create microtrauma and weakening of the anterior bundle of the UCL, potentially leading to instability or rupture (8,9). Complete disruption of the anterior bundle of
the UCL destabilizes the elbow against valgus stress encountered during the acceleration phase. From the performance perspective, this throwing rendering disruption renders forceful overhead throwing nearly impossible.

When discussing UCL injury, understanding severity is important for sports medicine providers to be aware of the nomenclature and treatment recommendations based upon severity, as referenced in Figure 2. One categorization includes grade 1 as an intact ligament with or without edema, grade 2a is a partial tear and grade 2b is a chronic healed injury, and grade 3 is a complete tear (10). There also is a newer six-stage UCL grading scheme. The stages are based on location of tear (proximal/humeral, midsubstance, or distal/ulnar) and if the UCL injury was a partial tear or complete tear (11). Both of these grading schemes use MRI imaging.

Figure 1: Ulnar collateral ligament anatomy.

Epidemiology of UCL Injury and Rupture

The incidence of UCL rupture in baseball players has increased by more than 9% in 15- to 19-year-olds between 2007 and 2011 (12). At a professional level, 15% of minor league pitchers and nearly 25% of Major League Baseball (MLB) pitchers have a history of UCL-R (13). The most recent data from MLB revealed that 24.1% of all elbow injuries from 2011 to 2014 were due to UCL related injury (14). UCL-R rates at the collegiate baseball level are 2.5 per 100 player-seasons with pitchers nearly double that rate at 4.4 per 100 player-seasons (15). Recent NCAA surveillance data indicate that the overall incidence of UCL injury in collegiate baseball players is 1.12 per 10,000 athletes (16). While media attention has primarily focused on professional baseball pitchers, any overhead athlete that performs high-velocity overhead rotation motions can incur a UCL injury. Athletes at risk include American football quarterbacks (17), javelin throwers (18), softball players (19), and athletes participating in water polo, gymnastics, wrestling, tennis, and golf (20,21). These injuries can be treated with different surgical approaches but involve reconstruction (or in some instances repair) of the UCL. UCL-R also is known as the “Tommy John Surgery,” named after the original operation performed in 1974 by Dr. Frank Jobe on former New York Yankees Pitcher, Tommy John. The use of this procedure has increased in adolescent and high school-aged baseball players during the last 20 years (3,12).

Figure 2: Treatment algorithm in UCL injuries in throwing athletes.
UCL-R rates for high school baseball players compared with older athletes increased from 8% to 13% from 1994 to 2003 (3). At one of the highest volume facilities that performs UCL-R, the proportion of youth and adolescent athletes who underwent UCL-R increased from less than 5% to more than 50% from 1994 to 2015 (22).

**Factors Driving Care Pathway for UCL Injury**

UCL injuries can result in loss of significant playing time. The treatment algorithm the authors recommend in Figure 2 reflects the complexities involved in the decision to treat an athlete with nonoperative or operative management. This decision is dependent on multiple factors, including severity, location, sport played, and responsiveness to initial nonoperative care. Complete ruptures of the UCL typically result in surgical intervention and mild sprains typically result in nonoperative management (23). However, decision making is challenging when there is a partial tear. The second factor is location of the UCL injury. Among professional baseball pitchers, distal UCL injuries result in greater likelihood of failing nonoperative treatment (12.4×) relative to proximal partial tears (24). Nearly 75% of partial tears failed nonoperative treatment (>50% ruptured) (24). It should be stated that although MRI arthrograms have a very high sensitivity for detecting abnormalities of the UCL, baseball players, and throwing athletes in general may be asymptomatic despite abnormal imaging (10). Additionally, ultrasonography with an experienced operator is another imaging modality that can be used to make a diagnosis of a UCL injury (25–27). Therefore, the authors recommend the combination of a clinical examination with imaging to make the diagnosis of a UCL injury. The third factor is the sport the athlete plays. Throwing athletes require the use of an intact UCL due to its function as a valgus stabilizer. The biomechanical stressors placed upon the medial elbow vary based on the throwing motion and object. For example, javelin throwers have greater forces on their medial elbow due to the throwing motion and the length and weight of the spear compared with American football quarterbacks who throw a smaller object with compact dimensions (28). Hence, a javelin thrower has a lower likelihood for successful return to sport when treated nonoperatively compared with a quarterback (17).

Fourth, if a patient sustains a sprain or a low-grade tear, a period of nonoperative management may be the most effective approach. At our institution, we recommend a period of nonthrowing physical therapy until the athlete is asymptomatic. We make sure that valgus force or strain exposure is minimized during this time. This period typically lasts approximately 6 wk. Then, if the patient is asymptomatic, a return-to-throwing program follows over the next approximate 6-wk period. If symptoms continue at relative rest or with the throwing program, then a surgical referral is placed.

While our program has evolved in recent years, the overall components have remained the same (23). A similar program has been described by Smucny and colleagues (29). They constructed their UCL rehabilitation program into three phases. Phase one lasts approximately 1 to 2 wk with goals of decreasing pain and swelling, protecting valgus stress, improving range of motion (except for shoulder external rotation to minimize elbow valgus stress), and strengthening of the elbow, wrist, hand, and shoulder. Phase 2, lasting approximately 4 wk, is intended to normalize strength, prepare to return to sports-related activity, and begin proprioceptive neuromuscular facilitation, as well as wrist and forearm strengthening.

Lastly, phase 3, which lasts approximately 6 wk, includes the return-to-throw program with a goal of return to sport. It should be noted that every athlete is different, and rehabilitation programs may be adjusted for each individual based on their sport and position (29). Their team has found success with nonoperative management and returning athletes to sport at the same level of competition with low-grade proximal UCL sprains (29).

**Orthobiologics**

Research into the usage of orthobiologics for UCL injuries has increased in the past few years. There are multiple studies using platelet-rich plasma (PRP), suggesting possible advantages to combining PRP with physical therapy after sprains or partial tears (30,31). Recommendations of when to consider usage of PRP include incomplete UCL tears, skeletally immature patients due to open physes, and for nonprofessional athletes who will be ending their careers and do not want to undergo surgical intervention and postoperative care (30). There are three recent case series studies using PRP in athletes with UCL injury (32–34). Podesta and colleagues used PRP in throwing athletes with partial thickness UCL tears on MRI that had failed nonoperative management after attempting to return to competitive play. All athletes received a single PRP injection performed with ultrasound guidance followed by physical therapy. Results indicated an 88% return to sport on average 12 wk after PRP was injected. Podesta’s team also noted the medial humeral-ulnar joint space gapping with valgus stress decreased by 8 to 9 mm at final follow-up after PRP injection; however, it is unclear if this was due to the PRP or due to the body’s healing mechanisms given the significant time since the injury occurred (32). Dines and colleagues injected PRP into 44 baseball players with MRI evidence of partial thickness UCL tears or sprains after failing conservative measures, such as PT and activity medication. Dines team reported a 73% success rate of return to sport. It should be noted that of the 29 patients with partial tears, 7 were distal, and all distal tears resulted in poor outcomes, reenforcing the outcomes by Frangiamore’s team (24,33). Deal et al. evaluated 25 athletes (23 baseball athletes, 2 softball athletes) with 23 of them sustaining grade 2 UCL injuries using MRA. Treatment included varus-loading elbow bracing, activity restriction, and physical therapy, augmented by two injections of PRP separated by 2 wk. Twenty-two of 23 patients returned to play at the same or higher level of competition without further intervention. The mean time to return to competitive sport was between 11 and 12 wk (34). In all three case series studies, there were no comparison groups; thus, it is unclear to what extent the PRP provided augmentation of healing as opposed to the body’s natural healing mechanisms. Of note, in all three studies, PRP was injected into the location of the tear of the UCL. There is one case report discussing the augmentation of UCL-R with a combination of a dermal allograft, PRP, and mesenchymal stem cells in a professional baseball pitcher and one recent case report on the use of PRP in a 14-year-old baseball pitcher with a partial UCL who recovered with PRP (35,36). However, research and published literature regarding the use of PRP in UCL injury is otherwise scarce. But, even with evidence-based
research, media attention on highly visible athletes leads the general public to inquire about treatment regimens that, although potentially promising, have not been confirmed to be 100% effective at this time (37,38).

Level of Performance after UCL-R

Although there is a significant amount of media attention when injury occurs and when elite athletes in MLB return to sport successfully, it is paramount to provide realistic expectations for success after a UCL-R in all levels of play. Sustaining a UCL rupture is a devastating injury to any thrower. It will cause significant disruption in a playing career and potentially result in retirement from sport. Evidence of UCL-R effects on performance enhancement is mixed. Postsurgical success is defined as return to the same or higher level of play after the procedure. In one retrospective, case-control study (n = 168), 87% of MLB pitchers returned to pitching, but had a performance decline in several areas, such as earned run average, walks and hits per inning, and total innings pitched (39). A second cohort study of publicly available records revealed that among MLB pitchers who underwent UCL-R (n = 147), 50% demonstrated performance decrements across multiple pitching performance parameters compared with preinjury levels and returned to the disabled list (40). In contrast, a large, retrospective epidemiology study of MLB pitchers (n = 790) showed significantly improved performance in multiple pitching performance metrics after UCL-R compared to pre-surgery (i.e., fewer losses, a lower losing percentage, lower earned run average, fewer walks, and allowed fewer hits, runs, and home runs) (2). With respect to pitching velocity, there is no significant increase in pitch velocity at the MLB level after the procedure with one study indicating a minimal increase of 0.6 mile·h⁻¹ in the average fastball the second year after UCL-R (41,43). It is not clear whether younger players can make greater postsurgical improvements in pitching velocity and performance than MLB players. When investigating other positions in comparison to pitchers, MLB catchers had a return to sport level ranging from 58% to 80% (44,45). MLB position players, in comparison to pitchers, return to sport (RTS) took approximately 11 months. In addition, return to participation in sport was significantly lower in players older than 30 years (53.3%) compared with players younger than 30 years (89.4%) (46).

The evidence indicates that some performance benefits such as pitching endurance may improve, but the pitching speed and other metrics may not consistently improve to preinjury levels. Given that multiple large studies reveal that UCL-R is successful in returning athletes to sport at the same level of competition or higher 75% to 94% of the time (1,43,45,47,48) throwers, family members, and coaches need to be educated that prophylactic UCL-R should not be performed to enhance performance, and UCL-R is not a guarantee to return to sport at the same level prior to injury (49).

Recovery Time From UCL-R and Return to Play

A prior study has revealed that coaches, parents, and players believe that return to play in baseball after UCL-R will generally take less than 9 months (49). This belief is likely fueled by the media’s portrayal of players who recover and return to competition after UCL-R by the following season (50). Misinformation on web sites is a source of recovery myths; a recent study found six web sites that suggest return to play in less than 9 months (51). Large scale studies have suggested that the average time to full competition varies from approximately 12 to 30 months among high school, collegiate, and professional players, with more than 1 year in younger pitchers (1,43,48,52–55). Unlike professional pitchers or collegiate pitchers who receive careful monitoring of rehabilitation, throwing biomechanical analysis, and return to throw programs, high school and adolescent players may not have access to the same resources and monitoring to help facilitate safe recovery within the same timeframe (47). In addition, there is evidence that high school aged athletes who undergo UCL-R have a lower return to play rate due to loss of interest, lack of opportunity, and continued elbow pain and discomfort (3,48). An important note is that age and other concurrent injuries may modify recovery from UCL-R. For example, players older than 30 years are more likely to incur flexor/pronator collateral ligament injury concurrent to UCL rupture (56). As such, the recovery from combined injuries may be more complicated and prolonged (57). Thus, the evidence suggests that recovery from UCL-R may take approximately a year to 15 months for mature baseball players without complications, but could take longer, depending on age, position, preinjury level of competition, and combined injuries (1,45,47,55). In addition, it is inappropriate to compare recovery times in high school athletes to professional athletes. Sports medicine team members should be aware of the challenges faced by adolescent athletes, including potential lack of access to resources, such as indoor training facilities, athletic trainers, and physical therapists, transportation options if those athletes do not drive, as well as limited time constraints due to school.

UCL-R Revisions

There is a growing trend of UCL-R complications, specifically graft failure (54,58–60). In fact, ESPN called it the “Revision Epidemic” in 2015 (61). The most recent data by Camp and colleagues found that the revision rate was 6.7% for all professional pitchers, 9.4% for MLB players, and 5.2% for Minor League Baseball players (55). Among all professional pitchers, multiple studies suggested approximately 15% required at least one revision surgery before the end of their career (43,58). Depending on the type of surgical technique performed, additional complications include ulnar neuritis, temporary ulnar nerve neuropraxia, synovitis, elbow stiffness, graft site complications, and medial epicondyle avulsion fracture (1,54,60,62,63). However, most seriously, there is clear evidence of UCL-R failure and required revision reconstruction. Recent data revealed 31% of retears occur within 4 years of UCL-R (64). Furthermore, speculation exists about why there has been a trend in UCL-R tear and growth in the number of revision procedures (65). A potential culprit includes the biomechanical loading pattern. Ever-increasing throwing velocities and the biomechanical stressors of repetitive throwing movement mechanically couple to cause tissue failure of the reconstructed area (41,66,67). This injury mechanism may be especially important in skeletally immature individuals (2,68,69). Adolescent pitchers who throw with velocities exceeding 85 mph may be 2.58 times more likely to sustain UCL injuries than pitchers who throw at slower velocities (70). Thus, throwing velocity may be one of the more important risk factors with regard to injury risk given the loads

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placed on the elbow and shoulder (71). Furthermore, emphasis on maintaining and participating in off-season and in-season throwing and strengthening programs is important for potential injury risk reduction.

Performance data on return to competition after revision UCL-R are more striking than after primary reconstruction (59,60). Specifically, MLB pitchers who underwent a UCL-R revision had a shorter career span in the major leagues than did control pitchers by approximately 0.8 to 2.4 years and only returned to MLB 65% of the time (45,58,59,72). A case series of adolescent athletes (including baseball players) who underwent UCL-R was designed to measure performance parameter differences between relief pitchers and starting pitchers (54). Starting pitchers would bear an increased workload by throwing more pitches in each game relative to the relief pitchers. Relief pitchers were able to resume 50% of their preinjury pitch workload, while starting pitchers only reached 35% of their prior workload. Relievers also demonstrated better earned run average, and strikeouts/walks per nine innings when compared with starters (73). This suggests that starting pitchers may be at higher risk for treatment failure in the revision setting, given the increased demands of the number of pitches thrown as a starting pitcher.

Therefore, the evidence points out that there is clearly a risk of rupture after UCL-R and that if one needs to undergo a revision reconstruction, likelihood of return to prior performance levels is significantly reduced.

UCL-Repair

Although UCL-R has been the surgical gold standard for an UCL injury that requires surgical intervention, there is clinical research with outcomes describing UCL-Repair. UCL repair may be a consideration if a younger athlete has sustained an acute UCL avulsion-type injury and/or if an athlete has no signs of a degenerated ligament with chronic degenerative changes (74). Promising data have revealed a return to sport time of 6 to 7 months with internal brace augmentation and 87% to 92% returned to the same level of competition or higher (75,76). While the surgical technique is beyond the scope of this manuscript, it is important for all sports medicine team members to be aware of this new surgical option.

Prevention of UCL Injuries

Prevention of overuse throwing injuries, particularly in the elbow, begins during youth baseball by following safety rules, pitch count, and rest days restrictions (77). Significant research has suggested that recommended adherence to throwing programs and prevention of throwing while fatigued can help reduce injury risk (69,77–81). One study discovered that throwing injury risk increased 5-fold for pitching more than 8 months per year, nearly fourfold for pitching more than 80 pitches per game and pitching often despite arm fatigue increased the risk for injury by 36 times (70).

A UCL rupture is an acute event; however, the mechanical events leading to the rupture accumulate over time from chronic repetitive wear and tear (82). Multiple studies have shown that high-velocity large excursion movements and valgus torque adversely impact the stabilizing structures of the elbow. Structural changes occur in the elbow that can compromise the integrity of the UCL and result in UCL deterioration injury (83–85).

Lastly, there are clinical features that may be a clue to aid in the prevention of UCL injuries. These include assessment of glenohumeral range of motion (86–88) and rotator cuff strength (89), use of dynamic ultrasound (25,26,90–92), and even scoring predictor systems such as the Kerlan-Jobe Orthopaedic Clinic (KJOC) Shoulder and Elbow Score (53). Clinicians should be aware and potentially use these assessment techniques to identify overhead throwers at risk for future injury. Specific examples that may allow for prediction of future throwing arm injuries include decreased rotator cuff strength in internal rotation and external rotation (89), decreased KJOC scores in combination with a history of upper extremity injury (93), pitchers with deficits of >5° in total rotation in their throwing shoulders (87), UCL heterogeneity and thickening, increased ulnohumeral joint space laxity, and enlarged ulnar nerve cross-sectional area with dynamic ultrasound (90).

Injury Prevention Programs

Although there is significant research of risk factors of over-throwing injury, risks for UCL injury in overhead throwing athletes, and treatment (operatively and nonoperatively) of UCL injury, there is no robust amount of research specific to injury prevention of UCL injury in overhead throwing athletes. In general, expert opinion has recommended that elbow injuries in baseball players at the youth level may be prevented by following published safety rules and recommendations for prevention of overuse throwing (81). From an overuse perspective, it is recommended that following appropriate pitch counts and days of rest should help to reduce overuse throwing injuries (77). However, recent data have suggested the volume of pitches thrown in a high school baseball game, when including all pitches off a mound during a game day, is actually 42% greater than just live game competition (94). Thus, participation in a preseason throwing program to prepare the dominant arm for the rigors of the season ahead is recommended for prevention of overuse throwing injury (95). At the youth level, a strength and stretching exercise program at least once per week can decrease the incidence rate of medial elbow injury by more than 50% compared to controls (96). Furthermore, an injury prevention program in overhead throwing athletes including core, leg, and hip strengthening as well as proper throwing mechanics is recommended (28,97,98). Biomechanical modeling data have suggested that increasing muscle-tendon force (specifically the flexor carpi radialis longus, flexor carpi radialis brevis, and flexor digitorum superficialis) through strengthening should decrease loads on the UCL, which theoretically should decrease risk of injury (99).

Prevention of UCL Injury in overhead throwers can be improved with continued education by the team of athletic trainers, physical therapists, and physicians that treat and care for this specific athletic population. Only through the use of grassroots education will the prevalence of this overhead throwing injury begin to reverse course. Specific examples can include but are not limited to referring athletes, parents, and coaches to well-known national web sites that provide free handouts on injury prevention (i.e., http://www.stopsportsinjuries.org/, http://www.sportsmedtoday.com/, and http://m.mlb.com/pitchsmart/), free lectures to the community from well-known experts and local team physicians, and smart phone applications that can provide educational information on throwing and preseason...
strengthening programs as well as pitch count monitoring (77,100,101). Directions of future research that have been initiated include identification of surgical aspects that predict long-term success (1,53,54,73), optimization of post-surgical rehabilitation for faster recovery (102), developing biomechanical evaluations in the preseason, and potential further applications of regenerative medicine on partial UCL tears and sprains (103–105). Other future directions of research may include the effects of education for coaches and educational strategies on public perceptions of the UCL injury and treatments. Ultimately, the true challenge is to prevent this injury from occurring in the first place.

Conclusions
Pitching mechanics, following rest day and pitch count restrictions, instructing our throwers on the correct way to pitch at an early age, appropriate off-season and in-season training workloads, and performing accurate clinical and biomechanical assessments in the preseason are all factors that in combination may allow for a reduction in the number of UCL injuries and subsequent reconstructions. While epidemiological studies of athletes from 13 years old to major leaguers are certainly concerning, the hope is that the enactment of injury prevention programs in the past few years will lead to a decreased incidence of UCL injuries in the next 5 to 10 years. Further research on treatment modalities for operative and nonoperative UCL injuries as well as long-term outcome studies will be required to limit the number of UCL injuries in overhead throwing athletes.

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