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

Jason L. Zaremski, MD, CAQSM, FAAPMR, FACSM;
Kevin R. Vincent, MD, PhD, CAQSM, FAAPMR, FACSM; and Heather K. Vincent, PhD, FACSM

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.

Department of Orthopaedics and Rehabilitation, University of Florida, Gainesville, FL

Address for correspondence: Jason L. Zaremski, MD, CAQSM, FAAPMR, FACSM, Division of PM&R, Sports Medicine & Research, Department of Orthopedics and Rehabilitation, UF Orthopaedics and Sports Medicine Institute, P.O. Box 112727, Gainesville, FL 32611; E-mail: zaremjl@ortho.ufl.edu.

1537-890X/1809/338–345
Current Sports Medicine Reports

Therefore, the goal of this manuscript will be to:

1. Provide an evidence-based summary of the surgical and nonsurgical treatment outcomes to better prepare care providers in counseling players, families, and coaches on the recovery after this injury.
2. Provide a reference and help guide physician-patient discussions and provide realistic expectations after sustaining this type of injury.

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 $N{\cdot}m^{-1}$) on the elbow is generated (6). However, the known tensile strength of the UCL is only 33 $N{\cdot}m^{-1}$ 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

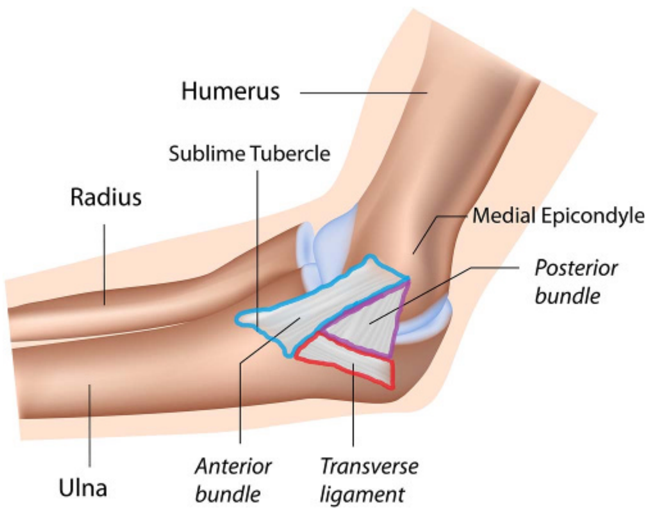

Figure 1: Ulnar collateral ligament anatomy.

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.

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).

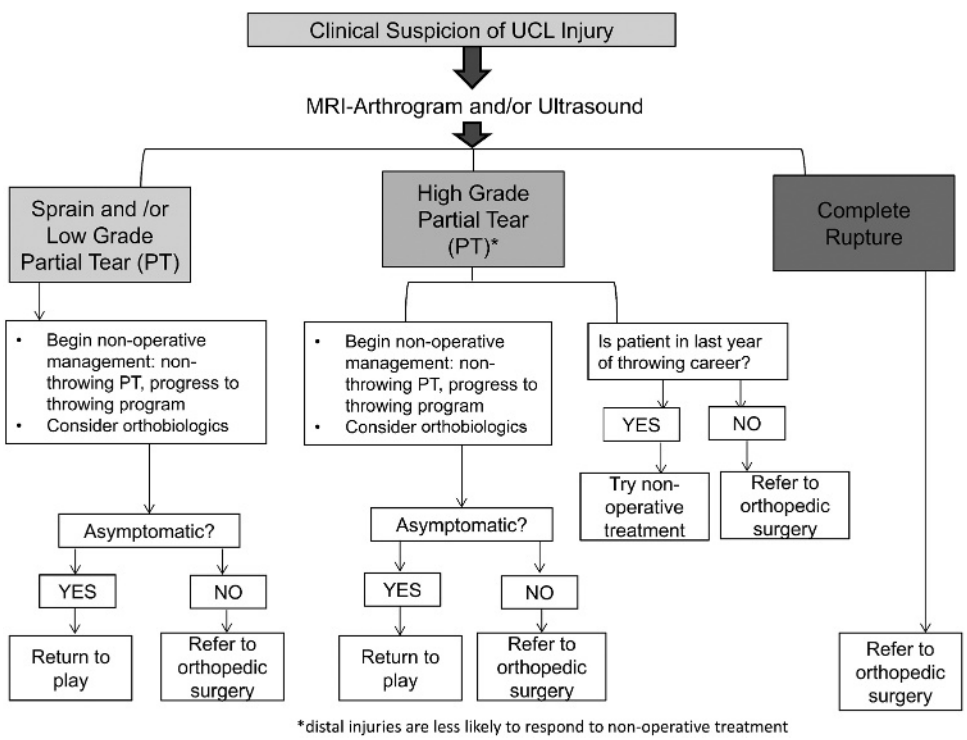

Figure 2: Treatment algorithm in UCL injuries in throwing athletes.

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 presurgery (*i.e.*, fewer losses, a lower losing percentage, lower earned run average, threw 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$\cdot$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 (1,2,43,48,52–55). 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 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 overhead 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 postsurgical 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.

The authors declare no conflict of interest and do not have any financial disclosure.

References

1. Cain EL, Andrews JR, Dugas JR, *et al.* Outcome of ulnar collateral ligament reconstruction of the elbow in 1281 athletes: results in 743 athletes with minimum 2-year follow-up. *Am. J. Sports Med.* 2010; 38:2426–34.
2. Erickson BJ, Gupta AK, Harris JD, *et al.* Rate of return to pitching and performance after Tommy John surgery in Major League Baseball pitchers. *Am. J. Sports Med.* 2014; 42:536–43.
3. Petty DH, Andrews JR, Fleisig GS, Cain EL. Ulnar collateral ligament reconstruction in high school baseball players: clinical results and injury risk factors. *Am. J. Sports Med.* 2004; 32:1158–64.
4. Regan WD, Korinek SL, Morrey BF, An KN. Biomechanical study of ligaments around the elbow joint. *Clin. Orthop. Relat. Res.* 1991; 271:170–9.
5. Dugas JR, Walters BL, Beason DP, *et al.* Biomechanical comparison of ulnar collateral ligament repair with internal bracing versus modified Jobe reconstruction. *Am. J. Sports Med.* 2016; 44:735–41.
6. Werner SL, Fleisig GS, Dillman CJ, Andrews JR. Biomechanics of the elbow during baseball pitching. *J. Orthop. Sports Phys. Ther.* 1993; 17:274–8.
7. O'Holleran JD, Altchek DW. The thrower's elbow: arthroscopic treatment of valgus extension overload syndrome. *HSS J.* 2006; 2:83–93.
8. Patel RM, Lynch TS, Amin NH, *et al.* The thrower's elbow. *Orthop. Clin. North Am.* 2014; 45:355–76.
9. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. *Am. J. Sports Med.* 1995; 23: 233–9.
10. Ford GM, Genuario J, Kinkartz J, *et al.* Return-to-play outcomes in professional baseball players after medial ulnar collateral ligament injuries: comparison of operative versus nonoperative treatment based on magnetic resonance imaging findings. *Am. J. Sports Med.* 2016; 44:723–8.
11. Ramkumar PN, Frangiamore SJ, Navarro SM, *et al.* Interobserver and intraobserver reliability of an MRI-based classification system for injuries to the ulnar collateral ligament. *Am. J. Sports Med.* 2018; 46:2755–60.
12. Erickson BJ, Nwachukwu BU, Rosas S, *et al.* Trends in medial ulnar collateral ligament reconstruction in the United States: a retrospective review of a large private-payer database from 2007 to 2011. *Am. J. Sports Med.* 2015; 43:1770–4.
13. Conte SA, Fleisig GS, Dines JS, *et al.* Prevalence of ulnar collateral ligament surgery in professional baseball players. *Am. J. Sports Med.* 2015; 43:1764–9.
14. Ciccotti MG, Pollack KM, Ciccotti MC, *et al.* Elbow injuries in professional baseball: epidemiological findings from the Major League Baseball injury surveillance system. *Am. J. Sports Med.* 2017; 45:2319–28.
15. Rothermich MA, Conte SA, Aune KT, *et al.* Incidence of elbow ulnar collateral ligament surgery in collegiate baseball players. *Orthop. J. Sports Med.* 2018; 6:2325967118764657.
16. DeFroda SF, Goodman AD, Gil JA, Owens BD. Epidemiology of elbow ulnar collateral ligament injuries among baseball players: National Collegiate Athletic Association Injury Surveillance Program, 2009–2010 through 2013–2014. *Am. J. Sports Med.* 2018; 46:2142–7.
17. Dodson CC, Slenker N, Cohen SB, *et al.* Ulnar collateral ligament injuries of the elbow in professional football quarterbacks. *J. Shoulder Elbow Surg.* 2010; 19: 1276–80.
18. Dines JS, Jones KJ, Kahlenberg C, *et al.* Elbow ulnar collateral ligament reconstruction in javelin throwers at a minimum 2-year follow-up. *Am. J. Sports Med.* 2012; 40:148–51.
19. Argo D, Trenhaile SW, Savoie FH 3rd, Field LD. Operative treatment of ulnar collateral ligament insufficiency of the elbow in female athletes. *Am. J. Sports Med.* 2006; 34:431–7.
20. Dugas J, Chronister J, Cain EL Jr., Andrews JR. Ulnar collateral ligament in the overhead athlete: a current review. *Sports Med. Arthrosc. Rev.* 2014; 22: 169–82.
21. Jobe FW, Stark H, Lombardo SJ. Reconstruction of the ulnar collateral ligament in athletes. *J. Bone Joint Surg. Am.* 1986; 68:1158–63.
22. American Sports Medicine Institute. Adolescent UCL Surgery ("Tommy John Surgery"). [Internet]. 2018. [cited 2019 July 23]. Available from: http://www.asmi.org/research.php?page=research&section=UCL.
23. Zaremski JL, McClelland J, Vincent HK, Horodyski M. Trends in sports-related elbow ulnar collateral ligament injuries. *Orthop. J. Sports Med.* 2017; 5:2325967117731296.
24. Frangiamore SJ, Lynch TS, Vaughn MD, *et al.* Magnetic resonance imaging predictors of failure in the nonoperative management of ulnar collateral ligament injuries in professional baseball pitchers. *Am. J. Sports Med.* 2017; 45:1783–9.
25. Atanda A Jr., Buckley PS, Hammoud S, *et al.* Early anatomic changes of the ulnar collateral ligament identified by stress ultrasound of the elbow in young professional baseball pitchers. *Am. J. Sports Med.* 2015; 43:2943–9.
26. Ciccotti MG, Atanda A Jr., Nazarian LN, *et al.* Stress sonography of the ulnar collateral ligament of the elbow in professional baseball pitchers: a 10-year study. *Am. J. Sports Med.* 2014; 42:544–51.
27. Kim NR, Moon SG, Ko SM, *et al.* MR imaging of ulnar collateral ligament injury in baseball players: value for predicting rehabilitation outcome. *Eur. J. Radiol.* 2011; 80:e422–6.
28. Zaremski JL, Wasser JG, Vincent HK. Mechanisms and treatments for shoulder injuries in overhead throwing athletes. *Curr. Sports Med. Rep.* 2017; 16: 179–88.
29. Smucny M, Westermann RW, Winters M, Schickendantz MS. Non-operative management of ulnar collateral ligament injuries in the throwing athlete. *Phys. Sportsmed.* 2017; 45:234–8.
30. Clark NJ, Desai VS, Dines JD, Morrey ME, Camp CL. Nonreconstruction options for treating medial ulnar collateral ligament injuries of the elbow in overhead athletes. *Curr. Rev. Musculoskelet. Med.* 2018; 11:48–54.
31. McCrum CL, Costello J, Onishi K, *et al.* Return to play after PRP and rehabilitation of 3 elite ice hockey players with ulnar collateral ligament injuries of the elbow. *Orthop. J. Sports Med.* 2018; 6:2325967118790760.
32. Podesta L, Crow SA, Volkmer D, *et al.* Treatment of partial ulnar collateral ligament tears in the elbow with platelet-rich plasma. *Am. J. Sports Med.* 2013; 41:1689–94.
33. Dines JS, Williams PN, ElAttrache N, *et al.* Platelet-rich plasma can be used to successfully treat elbow ulnar collateral ligament insufficiency in high-level throwers. *Am. J. Orthop.* 2016; 45:296–300.
34. Deal JB, Smith E, Heard W, *et al.* Platelet-rich plasma for primary treatment of partial ulnar collateral ligament tears: MRI correlation with results. *Orthop. J. Sports Med.* 2017; 5:2325967117738238.
35. Hoffman JK, Protzman NM, Malhotra AD. Biologic augmentation of the ulnar collateral ligament in the elbow of a professional baseball pitcher. *Case Rep. Orthop.* 2015; 2015:130157.
36. Gordon AH, De Luigi AJ. Adolescent pitcher recovery from partial ulnar collateral ligament tear after platelet-rich plasma. *Curr. Sports Med. Rep.* 2018; 17:407–9.
37. ESPN News Services. Angels' Shohei Ohtani placed on DL with sprained UCL, to be re-evaluated in 3 weeks. [Internet] 2018. [cited 2018 June 9]. Available from: http://www.espn.com/mlb/story/_/id/23735815/the-los-angeles-angels-placed-shohei-ohtani-disabled-list-sprained-ucl.

38. Moura P. Will stem cell therapy replace Tommy John surgery for baseball players? Angels pitchers may find out. *LA Times*. [Internet]. 2016. [cited 2018 June 9]. Available from: http://www.latimes.com/sports/angels/la-sp-angels-stem-cell-20160628-snap-story.html#.
39. Keller RA, Steffes MJ, Zhuo D, *et al*. The effects of medial ulnar collateral ligament reconstruction on Major League pitching performance. *J. Shoulder Elbow Surg*. 2014; 23:1591–8. doi:10.1016/j.jse.2014.06.033.
40. Makhni EC, Lee RW, Morrow ZS, *et al*. Performance, return to competition, and reinjury after Tommy John surgery in Major League Baseball pitchers: A review of 147 cases. *Am. J. Sports Med*. 2014; 42:1323–32.
41. Jiang JJ, Leland JM. Analysis of pitching velocity in Major League Baseball players before and after ulnar collateral ligament reconstruction. *Am. J. Sports Med*. 2014; 42:880–5.
42. Lansdown DA, Feeley BT. The effect of ulnar collateral ligament reconstruction on pitch velocity in Major League Baseball pitchers. *Orthop. J. Sports Med*. 2014; 2:2325967114522592.
43. Marshall NE, Keller RA, Limpisvasti O, ElAttrache NS. Pitching performance after ulnar collateral ligament reconstruction at a single institution in Major League Baseball pitchers. *Am. J. Sports Med*. 2018; 46:3245–53.
44. Marshall NE, Jildeh TR, Okoroha KR, *et al*. Performance, return to play, and career longevity after ulnar collateral ligament reconstruction in professional catchers. *Art Ther*. 2018; 34:1809–15.
45. Camp CL, Conte S, D'Angelo J, Fealy SA. Following ulnar collateral ligament reconstruction, professional baseball position players return to play faster than pitchers, but catchers return less frequently. *J. Shoulder Elbow Surg*. 2018; 27: 1078–85.
46. Jack RA 2nd, Burn MB, Sochacki KR, *et al*. Performance and return to sport after Tommy John surgery among Major League Baseball position players. *Am. J. Sports Med*. 2018; 46:1720–6.
47. Osbahr DC, Cain EL Jr., Raines BT, *et al*. Long-term outcomes after ulnar collateral ligament reconstruction in competitive baseball players: minimum 10-year follow-up. *Am. J. Sports Med*. 2014; 42:1333–42.
48. Saper M, Shung J, Pearce S, *et al*. Outcomes and return to sport after ulnar collateral ligament reconstruction in adolescent baseball players. *Orthop. J. Sports Med*. 2018; 6:2325967118769328.
49. Ahmad CS, Grantham WJ, Greiwe RM. Public perceptions of Tommy John surgery. *Phys. Sportsmed*. 2012; 40:64–72.
50. Conte SA, Hodgins JL, ElAttrache NS, *et al*. Media perceptions of Tommy John surgery. *Phys. Sportsmed*. 2015; 43:375–80.
51. Johnson CC, Garcia GH, Liu JN, *et al*. Internet resources for Tommy John injuries: what are patients reading? *J. Shoulder Elbow Surg*. 2016; 25:e386–93.
52. Gibson BW, Webner D, Huffman GR, Sennett BJ. Ulnar collateral ligament reconstruction in Major League Baseball pitchers. *Am. J. Sports Med*. 2007; 35: 575–81.
53. O'Brien DF, O'Hagan T, Stewart R, *et al*. Outcomes for ulnar collateral ligament reconstruction: a retrospective review using the KJOC assessment score with two-year follow-up in an overhead throwing population. *J. Shoulder Elbow Surg*. 2015; 24:934–40.
54. Jones KJ, Dines JS, Rebolledo BJ, *et al*. Operative management of ulnar collateral ligament insufficiency in adolescent athletes. *Am. J. Sports Med*. 2014; 42: 117–21.
55. Camp CL, Conte S, D'Angelo J, Fealy SA. Epidemiology of ulnar collateral ligament reconstruction in Major and Minor League Baseball pitchers: comprehensive report of 1429 cases. *J. Shoulder Elbow Surg*. 2018; 27:871–8.
56. Osbahr DC, Swaminathan SS, Allen AA, *et al*. Combined flexor-pronator mass and ulnar collateral ligament injuries in the elbows of older baseball players. *Am. J. Sports Med*. 2010; 38:733–9.
57. Hodgins JL, Trofa DP, Donohue S, *et al*. Forearm flexor injuries among Major League Baseball players: epidemiology, performance, and associated injuries. *Am. J. Sports Med*. 2018; 46:2154–60.
58. Wilson AT, Pidgeon TS, Morrell NT, DaSilva MF. Trends in revision elbow ulnar collateral ligament reconstruction in professional baseball pitchers. *J. Hand Surg. Am*. 2015; 40:2249–54.
59. Marshall NE, Keller RA, Lynch JR, *et al*. Pitching performance and longevity after revision ulnar collateral ligament reconstruction in Major League Baseball pitchers. *Am. J. Sports Med*. 2015; 43:1051–6.
60. Dines JS, Yocum LA, Frank JB, *et al*. Revision surgery for failed elbow medial collateral ligament reconstruction. *Am. J. Sports Med*. 2008; 36:1061–5.
61. Bell S. What we've missed about Tommy John surgery. ESPN.COM. [Internet]. 2018. [cited 2018 Sept 15]. Available from: http://www.espn.com/mlb/story/_/id/12648769/what-missed-tommy-john-surgery.
62. Vitale MA, Ahmad CS. The outcome of elbow ulnar collateral ligament reconstruction in overhead athletes: a systematic review. *Am. J. Sports Med*. 2008; 36:1193–205.
63. Clain JB, Vitale MA, Ahmad CS, Ruchelsman DE. Ulnar nerve complications after ulnar collateral ligament reconstruction of the elbow: a systematic review. *Am. J. Sports Med*. 2019; 47:1263–9.
64. DeFroda SF, Kriz PK, Hall AM, *et al*. Risk stratification for ulnar collateral ligament injury in Major League Baseball players: a retrospective study from 2007 to 2014. *Orthop. J. Sports Med*. 2016; 4:2325967115627126.
65. Bruce JR, ElAttrache NS, Andrews JR. Revision ulnar collateral ligament reconstruction. *J. Am. Acad. Orthop. Surg*. 2018; 26:377–85.
66. Fast M. Lose a tick, gain a tick. Hardball Times. [Internet]. 2010. [cited 2016 April 5]. Available from: http://www.hardballtimes.com/lose-a-tick-gain-a-tick/.
67. Hurd WJ, Jazayeri R, Mohr K, *et al*. Pitch velocity is a predictor of medial elbow distraction forces in the uninjured high school-aged baseball pitcher. *Sports Health*. 2012; 4:415–8.
68. Limpisvasti O, ElAttrache NS, Jobe FW. Understanding shoulder and elbow injuries in baseball. *J. Am. Acad. Orthop. Surg*. 2007; 15:139–47.
69. Mautner BK, Blazuk J. Overuse throwing injuries in skeletally immature athletes—diagnosis, treatment, and prevention. *Curr. Sports Med. Rep*. 2015; 14:209–14.
70. Olsen SJ 2nd, Fleisig GS, Dun S, *et al*. Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *Am. J. Sports Med*. 2006; 34:905–12.
71. Dun S, Loftice J, Fleisig GS, *et al*. A biomechanical comparison of youth baseball pitches: is the curveball potentially harmful? *Am. J. Sports Med*. 2008; 36: 686–92.
72. Liu JN, Garcia GH, Conte S, *et al*. Outcomes in revision Tommy John surgery in Major League Baseball pitchers. *J. Shoulder Elbow Surg*. 2016; 25:90–7.
73. Jones KJ, Conte S, Patterson N, *et al*. Functional outcomes following revision ulnar collateral ligament reconstruction in Major League Baseball pitchers. *J. Shoulder Elbow Surg*. 2013; 22:642–6.
74. Rebolledo BJ, Dugas JR, Bedi A, *et al*. Avoiding Tommy John surgery: what are the alternatives? *Am. J. Sports Med*. 2017; 45:3143–8.
75. Dugas JR, Looze CA, Capogna B, *et al*. Ulnar collateral ligament repair with collagen-dipped fibertape augmentation in overhead-throwing athletes. *Am. J. Sports Med*. 2019; 47:1096–102.
76. Erickson BJ, Bach BR Jr., Verma NN, *et al*. Treatment of ulnar collateral ligament tears of the elbow: is repair a viable option? *Orthop. J. Sports Med*. 2017; 5:2325967116682211.
77. Major League Baseball. Pitch Smart. [Internet]. 2016. [cited 2016 Aug 31]. Available from: http://m.mlb.com/pitchsmart/pitching-guidelines/.
78. Kerut EK, Kerut DG, Fleisig GS, Andrews JR. Prevention of arm injury in youth baseball pitchers. *J. La. State Med. Soc*. 2008; 160:95–8.
79. Parks ED, Ray TR. Prevention of overuse injuries in young baseball pitchers. *Sports Health*. 2009; 1:514–7.
80. Zaremski JL, Krabak BJ. Shoulder injuries in the skeletally immature baseball pitcher and recommendations for the prevention of injury. *PM R*. 2012; 4: 509–16.
81. Fleisig GS, Andrews JR. Prevention of elbow injuries in youth baseball pitchers. *Sports Health*. 2012; 4:419–24.
82. Bruce JR, Andrews JR. Ulnar collateral ligament injuries in the throwing athlete. *J. Am. Acad. Orthop. Surg*. 2014; 22:315–25. doi:10.5435/JAAOS-22-05-315.
83. Kancherla VK, Caggiano NM, Matullo KS. Elbow injuries in the throwing athlete. *Orthop. Clin. North Am*. 2014; 45:571–85.
84. Hariri S, McAdams TR. Nerve injuries about the elbow. *Clin. Sports Med*. 2010; 29:655–75.
85. Loftice J, Fleisig GS, Zheng N, Andrews JR. Biomechanics of the elbow in sports. *Clin. Sports Med*. 2004; 23:519–30, vii-viii.
86. Dines JS, Frank JB, Akerman M, Yocum LA. Glenohumeral internal rotation deficits in baseball players with ulnar collateral ligament insufficiency. *Am. J. Sports Med*. 2009; 37:566–70.
87. Wilk KE, Macrina LC, Fleisig GS, *et al*. Deficits in glenohumeral passive range of motion increase risk of elbow injury in professional baseball pitchers: a prospective study. *Am. J. Sports Med*. 2014; 42:2075–81.
88. Miyashita K, Urabe Y, Kobayashi H, *et al*. The role of shoulder maximum external rotation during throwing for elbow injury prevention in baseball players. *J. Sports Sci. Med*. 2008; 7:223–8.
89. Garrison JC, Johnston C, Conway JE. Baseball players with ulnar collateral ligament tears demonstrate decreased rotator cuff strength compared to healthy controls. *Int. J. Sports Phys. Ther*. 2015; 10:476–81.
90. Keller RA, Marshall NE, Bey MJ, *et al*. Pre- and postseason dynamic ultrasound evaluation of the pitching elbow. *Art Ther*. 2015; 31:1708–15.
91. Bica D, Armen J, Kulas AS, *et al*. Reliability and precision of stress sonography of the ulnar collateral ligament. *J. Ultrasound Med*. 2015; 34:371–6.

92. Sasaki J, Takahara M, Ogino T, *et al*. Ultrasonographic assessment of the ulnar collateral ligament and medial elbow laxity in college baseball players. *J. Bone Joint Surg. Am*. 2002; 84:525–31.

93. Franz JO, McCulloch PC, Kneip CJ, *et al*. The utility of the KJOC score in professional baseball in the United States. *Am. J. Sports Med*. 2013; 41:2167–73.

94. Zaremski JL, Zeppieri G Jr., Jones DL, *et al*. Unaccounted workload factor: game-day pitch counts in high school baseball pitchers-an observational study. *Orthop. J. Sports Med*. 2018; 6:2325967118765255.

95. Axe M, Hurd W, Snyder-Mackler L. Data-based interval throwing programs for baseball players. *Sports Health*. 2009; 1:145–53.

96. Sakata J, Nakamura E, Suzuki T, *et al*. Efficacy of a prevention program for medial elbow injuries in youth baseball players. *Am. J. Sports Med*. 2018; 46: 460–9.

97. Wilk KE, Arrigo CA, Hooks TR, Andrews JR. Rehabilitation of the overhead throwing athlete: there is more to it than just external rotation/internal rotation strengthening. *PM R*. 2016; 8(Suppl. 3):S78–90.

98. Fleisig GS, Diffendaffer AZ, Ivey B, *et al*. Changes in youth baseball pitching biomechanics: a 7-year longitudinal study. *Am. J. Sports Med*. 2018; 46: 44–51.

99. Buffi JH, Werner K, Kepple T, Murray WM. Computing muscle, ligament, and osseous contributions to the elbow varus moment during baseball pitching. *Ann. Biomed. Eng*. 2015; 43:404–15.

100. Sports Medicine Today. [Internet]. 2019. [cited 2019 May 1]. Available from: https://www.sportsmedtoday.com/.

101. American Orthopaedic Society for Sports Medicine. STOP Sports Injuries: Sports Injury Prevention. [Internet]. 2019. [cited 2019 May 1]. Available from: https://www.stopsportsinjuries.org/.

102. Ellenbecker TS, Wilk KE, Altchek DW, Andrews JR. Current concepts in rehabilitation following ulnar collateral ligament reconstruction. *Sports Health*. 2009; 1:301–13.

103. Fleisig G, Chu Y, Weber A, Andrews J. Variability in baseball pitching biomechanics among various levels of competition. *Sports Biomech*. 2009; 8:10–21.

104. Fleisig GS, Leddon CE, Laughlin WA, *et al*. Biomechanical performance of baseball pitchers with a history of ulnar collateral ligament reconstruction. *Am. J. Sports Med*. 2015; 43:1045–50.

105. Kato Y, Yamada S, Chavez J. Can platelet-rich plasma therapy save patients with ulnar collateral ligament tears from surgery? *Regen Ther*. 2019; 10: 123–6.