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CLINICAL FEATURE
REVIEW

Non-operative management of ulnar collateral ligament injuries in the throwing athlete

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ABSTRACT
Medial ulnar collateral ligament (UCL) injuries have become increasingly prevalent in overhead athletes. The orthopaedic literature contains a wealth of information on operative management of these injuries. However, there are few high-quality longitudinal studies on non-operative care of UCL injuries. The purpose of this review is to describe the non-operative approach to managing UCL injuries, including recommended rehabilitation strategies and predictors of successful non-operative treatment.

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1. Introduction

Medial ulnar collateral ligament (UCL) injuries to the elbow are becoming increasingly recognized in overhead athletic populations. The incidence of UCL reconstruction has more than doubled over the past decade in major league baseball, and it is currently estimated that 10% of minor league and professional players have undergone UCL reconstruction and 25% of professional pitchers had undergone reconstruction [1,2]. UCL injuries are increasingly affecting young athletes under the age of 20, and the overall number of UCL reconstruction procedures in 15–19 year olds in the United States has experienced an annual growth of 9.84% [3]. A recent review of one state found that the number of UCL reconstructions more than quadrupled from 21 in 2003 to 93 in 2014, with a disproportionate increase among 15–19-year-old patients [4]. The majority of the current literature on management mirrors this trend and is skewed toward operative outcomes. There are a paucity of studies that report the results and predictors of success of non-operative treatment of UCL tears in throwing athletes [5–7]. The majority of injuries to the UCL, however, have classically not required surgery. One study found that 84% of professional baseball players with partial UCL injury on MRI successfully returned to play after completing non-operative rehabilitation [6]. Professional quarterbacks who suffered UCL injuries were able to return to football in 90% of cases without surgical intervention at a mean of 26 days [8]. The purpose of this review is to describe the approach to non-operative management of the UCL and describe prognostic factors that may predict successful non-operative management.

2. History and physical exam

Familiarity with the differential diagnosis for thrower's elbow pain guides the history and physical exam. The possible causes for medial-sided elbow pain include UCL injury, ulnar neuropathy, flexor–pronator strain, medial epicondylitis, valgus extension overload, medial epicondyle apophysitis or avulsion fracture, and olecranon apophysitis or stress fracture. With these possible diagnoses in mind one can frame specific questions on history to identify a UCL tear and its associated injuries.

For any throwing athlete with an elbow issue it is important to establish the chief complaint and timing of injury. Common complaints for UCL injury are a loss of throwing velocity or control and associated medial elbow pain. Pain is usually greatest during the late cocking and early acceleration phases of throwing, when the valgus torque on the elbow is at its greatest [9]. Beyond these typical symptoms, the patient may also have complaints due to associated medial-sided injuries such as pain with resisted wrist flexion and pronation due to strain of the flexor–pronator muscles, mechanical symptoms or posteromedial elbow pain at terminal extension due to valgus extension overload, or paresthesias in the ulnar nerve distribution due to ulnar neuropathy. Up to 40% of patients with significant UCL injury experience ulnar nerve symptoms [10]. UCL tears are usually chronic and progressive with a gradual decline in throwing performance, but they can also have an acute presentation with a 'pop' and sharp medial pain or they can present as an acute injury with prodromal symptoms [11].

On physical exam, inspection of the elbow may reveal medial ecchymosis or swelling. Patients typically have decreased range of motion. Palpation of the anterior bundle of the UCL has high sensitivity (81–94%) but reportedly low specificity (22%) due to the proximity of the flexor–pronator mass and ulnar nerve [12]. Ranging the elbow from 90° of flexion to approximately 50–70° will displace the flexor–pronator mass anteriorly and may allow more specific palpation of the UCL posteriorly along its course from the medial epicondyle to the sublime tubercle of the ulna [13].

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Valgus stability of the elbow should be assessed with the forearm fully pronated and the elbow flexed to 20–30° to unlock the olecranon from its fossa [13]. A significantly softer end point or medial-sided pain is suspicious for UCL injury. An increased opening to valgus stress may not necessarily be pathologic in the dominant arm of a throwing athlete as these changes can be adaptive and asymptomatic [14]. The milking maneuver is performed with humerus adducted, the forearm fully supinated, and the elbow flexed to approximately 120°. The thumb is then pulled laterally by either the examiner or the patient's contralateral extremity to create a valgus force on the elbow, with pain, instability, or apprehension indicative of UCL injury. Perhaps the best test for UCL tear is the moving valgus stress test, with reported sensitivity of 100% and specificity of 75% [15]. Here, the examiner applies and maintains a constant valgus torque to the fully flexed elbow and then quickly extends the elbow. A positive finding is medial elbow pain at the location of the UCL, most pronounced between 120° and 70°.

As with taking a history, concurrent pathology should be assessed on physical exam in every thrower with suspected UCL tear. At a minimum the examiner should check for ulnar neuropathy, valgus extension overload (posteromedial elbow pain which can be accentuated at terminal extension with valgus stress), and flexor–pronator issues.

3. Diagnostic imaging

Anterior–posterior and lateral plain radiographs of a painful elbow are useful to evaluate acute avulsions of the sublime tubercle or heterotopic ossification in a chronically injured UCL [16,17]. The oblique axial view may be particularly helpful to detect loose bodies or osteophytes by the posteromedial olecranon [18]. Over half of all patients with UCL injury may have a radiographic abnormality such as an olecranon osteophyte or calcification within the UCL [19]. Even on routine elbow radiographs of asymptomatic major league baseball pitchers, there may be an 11% incidence of UCL ossification [20]. Stress radiography was classically performed to assess for UCL injury; however, it has not routinely proven to be beneficial in diagnosis or management, especially in the age of magnetic resonance imaging (MRI) and improved ultrasound technique [11,21].

MRI has become the modality of choice to detect UCL tears. Non-contrast 1.5-tesla MRI has a sensitivity of 60–80% and specificity of 100% [22]. Magnetic resonance arthrogram or 3-tesla MRI allows for even greater sensitivity, particularly for partial tears [23]. Partial tears are represented by the 'T-sign,' as described by Timmermann et al. where contrast from CT arthrography leaked around the detachment of the UCL from its bony insertion but remained contained within the intact superficial layer of the UCL and capsule [22]. It is important not to confuse the normal attachment of the UCL (up to 2.8 mm from the articular surface of the ulna) with the 'T-sign' [24].

Ultrasound has gained popularity recently as it can be performed in clinic and be used dynamically with valgus stress to assess the UCL. Stress ultrasound can detect 1.0 mm or more of joint gapping with a sensitivity of 96% and specificity of 81%. It has similarly high sensitivity and specificity in detecting concurrent ulnar neuritis or myotendinous injury [23].

4. Rehabilitation guidelines for non-operative care

Non-operative care should be the initial treatment choice in most cases of UCL injury, and rehabilitation is a slowly progressive process. The recommendations that follow are based on existing literature as well as clinical experience [5,6,25,26]. In the initial phase following injury, the goals are to reduce pain, control medial stress, and restore pain-free elbow and shoulder range of motion. Complete rest and anti-inflammatory medications are recommended, with possible use of a hinged elbow brace to protect the elbow from valgus stress. Braces should prevent full extension for the first two weeks and then gradually expand the range of motion afterward. Modalities to control pain such as ultrasound, interferential current, and iontophoresis are considered. As pain decreases, a therapy plan may commence (see Table 1). The initial strengthening program will include isometric elbow flexion/extension, wrist flexion/extension, and gripping exercise, as well as shoulder motion and scapular strengthening. However, range of motion exercises should avoid external rotation of the shoulder to avoid valgus stress at the elbow. For shoulder exercise, utilize cuff weights to reduce gripping stress. Conditioning work may utilize machines such as bike or elliptical (holding stationary grips).

Once pain-free with tolerance to valgus stress and minimal tenderness, the athlete may progress to phase 2. The goals at this

Table 1. Sample UCL rehabilitation protocol by phase.

Phase	Goals	Possible exercises
1 (1–2 weeks)	• Decrease pain and swelling: ice, compression sleeve, medication, other modalities • Protect valgus stress: ±brace, no ER stretching • Carefully build motion and maintain tone	• Normalize range of motion of shoulder and elbow (except shoulder ER) • Isometric strengthening of elbow, wrist, grip • Shoulder strengthening (cuff weights) • Cardiopulmonary exercise (stationary grips)
2 (2–6 weeks)	• Normalize strength • Prepare to move into sporting activity	• Isotonic strengthening of elbow • Manual PNF and wrist/forearm strengthening (start with proximal lever arm) • Activities in 90° shoulder abduction and ER ('90/90') • Plyometrics

3
(6–12 weeks)
	• Return to sport	• Sample plyometric program (2-hand: 4–8 pound medicine ball; 1-hand: 0.5–2 pound):
		  • 2-hand chest pass
		  • 2-hand overhead chop
		  • 2-hand diagonal chop
		  • 2-hand slam straight down
		  • 1-hand 90/90
		  • 1-hand IR at neutral
		  • 1-hand ER at neutral
		  • wall dribble at 90/90 position
		  • ER flip at 90/90 into wall
		  • Drop/catch ball at 90 flexion and abduction
		• Progressive interval throwing program (Table 2)

These exercises serve as guidelines and may be adjusted per provider preference.
ER: external rotation; PNF: proprioceptive neuromuscular facilitation.

stage are to normalize strength and prepare to move into sport-specific activity. More intense strengthening begins with progression to isotonic elbow, wrist, and forearm work. The eccentric phase of movement should be emphasized. Manual resistance can also be initiated for shoulder proprioceptive neuromuscular facilitation (PNF) diagonals and wrist and forearm movements. Initially this should be done with a more proximal lever arm to reduce force, with progression to distal force. Modalities may be continued to control any pain or swelling.

Prior to consideration of a return-to-throw program, the athlete should complete a series of plyometric exercises using a medicine ball. These begin with two-handed activities to reduce stress on the injured elbow, with progression to single-hand activities. The goal is to gradually increase the intensity by decreasing contact time (amortization phase) which will prepare the athlete for the higher-level activity of throwing.

The final return-to-sport phase may be initiated after completion of the preceding activities and with a satisfactory clinical exam (elbow has normal strength and is pain-free to valgus stress). This is typically after a period of 6 weeks or more. The final phase is individualized to the athlete, depending on sport and position. For all athletes, a proper warm-up prior to activity is required, including light cardio and dynamic warm-up with plyometrics. The general tenets of a return-to-play progression are a stepwise program where a single variable (intensity or volume) is increased at each level. Ability to complete a phase with good performance and without pain will dictate advancement to the next step.

For throwers, a return-to-sport interval throwing program (ITP) should be employed. A sample ITP is provided in Table 2. During the ITP, it is paramount to emphasize correct throwing mechanics along the entire kinetic chain – from lower extremity through the pelvis and trunk to the throwing arm. Biomechanical data support that correct pitching technique will lower humeral internal rotation torque and elbow valgus load [27,28]. The ITP may take 6–8 weeks to complete. In general, a throwing athlete will require a week of a return-to-throwing program per week of rest from throwing (so, for 6 weeks of shut down, minimum 6 weeks to return to a game-ready state for a total of 12 weeks of non-operative recovery). Throwers whose symptoms resolve with less than 3 weeks of rest and rehabilitation may advance to return to throwing sooner. In these cases, an accelerated interval throwing program (AITP) may be used. Principles of the AITP echo those of the regular ITP. A long toss program is initiated on level ground, progressing to pitching on level ground, followed by pitching on the mound. A sample 2-week pitching program is provided in Table 3.

Another key component in the management of UCL injury is to define the cause of injury and determine if any adjustments in training or shoulder mechanics can be made. As highlighted earlier, throwing mechanics is critical and should be evaluated and addressed in the ITP. Total rotation deficits have been linked with UCL injury in pitchers – if present, shoulder motion deficits should be addressed as part of the rehabilitation program [29,30]. Additionally, several studies have identified training risk factors for UCL injury. For example, Whiteside et al. found a significantly increased risk for UCL reconstruction in professional pitchers who took fewer days of rest between games, threw more pitches per game, had less pitch variation, and had a higher mean pitch velocity [31]. Chalmers et al. similarly found that higher peak and mean pitch velocity were predictors of UCL reconstruction among major league pitchers [32]. Other

Table 2. Sample Interval Throwing Program (ITP).

Phase	Distance	First block	Second block	Phase	Distance	First block	Second block
1 (0–1 week)	45 ft	• Warm-up throws • 25 throws • 15-min rest • Warm-up throws • 25 throws	• Warm-up throws • 25 throws • 10-min rest • Warm-up throws • 25 throws • 10-min rest • Warm-up throws • 25 throws	4 (3–4 weeks)	75–90 ft	• Warm-up throws • 5 throws at 70 ft • 5 throws at 80 ft • 5 throws at 85 ft • 10 throws at 90 ft • 10 throws at 95 ft • 10-min rest • Repeat program	• Warm-up throws • 5 throws at 70 ft • 5 throws at 80 ft • 10 throws at 85 ft • 10 throws at 90 ft • 10 throws at 95 ft • 10-min rest • Repeat program
2 (1–2 weeks)	60 ft	• Warm-up throws • 25 throws • 15-min rest • Warm-up throws • 25 throws	• Warm-up throws • 25 throws • 10-min rest • Warm-up throws • 25 throws • 10-min rest • Warm-up throws • 25 throws	5 (4–5 weeks)	90–115 ft	• Warm-up throws • 5 throws at 90 ft • 5 throws at 95 ft • 10 throws at 100 ft • 10 throws at 110 ft • 10 throws at 115 ft • 10-min rest • Repeat program	• Warm-up throws • 5 throws at 90 ft • 10 throws at 95 ft • 10 throws at 100 ft • 10 throws at 110 ft • 10 throws at 115 ft • 10-min rest • Repeat program
3 (2–3 weeks)	70–80 ft	• Warm-up throws • 5 throws at 60 ft • 10 throws at 70 ft • 10 throws at 75 ft • 10 throws at 80 ft • 10-min rest • Repeat program	• Warm-up throws • 10 throws at 70 ft • 15 throws at 75 ft • 15 throws at 80 ft • 15-min rest • Repeat program	6 (5–6 weeks)	90–120 ft	• Warm-up throws • 5 throws at 90 ft • 5 throws at 95 ft • 10 throws at 100 ft • 10 throws at 110 ft • 10 throws at 115 ft • 10 throws at 120 ft • 10-min rest • Repeat program	• Warm-up throws • 5 throws at 90 ft • 5 throws at 95 ft • 10 throws at 100 ft • 10 throws at 110 ft • 15 throws at 115 ft • 15 throws at 120 ft • 10-min rest • Repeat program

Adapted with permission from Ref. [26, Appendix 2].
Each block is approximately 3–4 days, such that each phase lasts 1 week.

Table 3. Sample accelerated interval throwing program (ITP).

Day	Distance	Throws
1–2	90 ft	2 sets of 25 throws
3	Rest	
4–5	120 ft	2 sets of 25 throws
6	Rest	
7	60 ft	Warm up, gradual increase velocity 25 fastball pitches on flat ground
8	Rest	
9	60 ft	See day 7, add change-up
10	60 ft	See day 9, add breaking balls
11	Rest	
12	60 ft	Pitching from the mound with fastballs
13	60 ft	Throw all pitches from mound with full effort, 35 pitches max May compete if completes all pitches without pain, and with good velocity and accuracy

Adapted with permission from Ref. [26, Appendix 1].
Typical 2-week program for pitcher with mild injury requiring less than 2 weeks of rest.

evidence shows that professional pitchers who used a fast ball for more than half of their pitches (i.e. less pitch variation and higher mean pitch velocity) were more likely to sustain a UCL injury [33]. These findings are echoed in younger throwers. A multivariable analysis on predictors of shoulder and elbow injury in adolescent pitchers found a 5-fold increased risk in those who pitched over 8 months per year, a 4-fold increased risk in those who pitched more than 80 pitches per game, a 2.5-fold increased risk in those who pitched a fastball greater than 85 miles per hour, and a *36-fold* increased risk in those who pitched despite arm fatigue [34]. Thus, at all levels it is important to recommend adequate rest between games, limited pitch counts, and a variety of pitches (to constrain the percentage of high-velocity fastballs).

5. Biologics

There has been increasing interest on the use of biologics to aid recovery from a UCL injury. A case series from Podesta et al. evaluated 34 athletes who had failed 2 months of non-operative treatment and found 88% of athletes were able to return to throwing at an average of 12 weeks following platelet-rich plasma (PRP) injection and physical therapy [35]. Dines et al. conducted a retrospective review of 44 baseball players who received one to three injections of PRP after failing an initial trial of conservative treatment for partial UCL tear [36]. They found that 34% were able to return to the same level of sport and 38% returned to a lower level of competitive play at an average of 12 weeks after injection. However all seven patients with distally based partial tears were unable to return to baseball at even a recreational level (see 'Location of Tear', below). To our knowledge there are no published reports on the use of bone marrow aspirate concentrate in UCL injury. The studies on PRP represent small retrospective case series; better quality data are required to further investigate this potentially promising effect.

6. Classification of tear, location of tear, and treatment algorithm

UCL injuries are typically described as either a sprain, partial tear (low- or high-grade based on thickness that is torn), or complete tear. Grade of tear along with player history may affect management, although there is no high-quality evidence to support this. Kim et al. found that of 39 baseball players who received a minimum of 6-weeks rehabilitation treatment, 27 went on to surgery. The surgical patients were more likely to have high-grade or complete tears (22 out of 27 patients), whereas the non-operative group consisted of primarily sprained or low-grade partial tears (10 out of 12 patients) [25]. In an evaluation of return to play in professional baseball pitchers by Ford et al., 15 players were treated with surgery and 28 with rehabilitation. Indications for surgery were complete tear or failed non-operative management of partial tear (six players, average 46 days of rehabilitation before surgery). There was a trend toward higher return to same level of play for partial versus complete tears (92% vs. 63%, $p = 0.05$) [6].

In addition to grade of injury, the location of tear may also predict failure of non-operative management. Some authors have not shown a difference in tear location (distal versus proximal) and outcomes of non-operative management [6,25]. But in a recent study by Frangiamore et al., the likelihood for failing non-operative management among 32 professional pitchers was 12.4 times greater ($p = 0.02$) for distal UCL tears than proximal tears, and when combining high-grade tear with distal location, seven of eight pitchers failed non-operative care [7]. Sixty-six percent of the pitchers successfully returned to the same level of play with non-operative management. Additionally, Dines et al. found that in their case series, none of the baseball players with partial distal tears were able to return to play after PRP injection and non-operative care [36].

Higher quality evidence is needed to draw firm conclusions, but based on available studies we make the following recommendations for high-level adult throwers, particularly baseball: (1) We recommend MRI to evaluate UCL tear grade and location. (2) Throwers with distally based tears or with complete tears may be more likely to fail non-operative treatment; this should be part of the initial treatment discussion with the patient. (3) Surgical reconstruction can be considered in those athletes who have no relief despite 6 weeks of rest and appropriate rehabilitation or who are unable to complete their ITP.

7. Conclusion

Non-operative management of sprains of the medial UCL of the elbow should be considered as first-line treatment in the majority of cases. After adequate rest, a structured ITP is crucial for successful return. Prevention of further injury may be provided by evaluating the athlete's throwing technique and training regimen. A high percentage of athletes, particularly those with low-grade proximal injuries, can enjoy successful return to play at the same level of competition.

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Declaration of interest

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References

1. 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 Sport Med. 2014;42(3):536–543.
2. Conte SA, Fleisig GS, Dines JS, et al. Prevalence of ulnar collateral ligament surgery in professional baseball players. Am J Sport Med. 2015;43(7):1764–1769.
3. 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 Sport Med. 2015;43(7):1770–1774.
4. Mahure SA, Mollon B, Shamah SD, et al. Disproportionate trends in ulnar collateral ligament reconstruction: projections through 2025 and a literature review. J Shoulder Elb Surg. 2016;25(6):1005–1012.
5. Rettig AC, Sherrill C, Snead DS, et al. Nonoperative treatment of ulnar collateral ligament injuries in throwing athletes. Am J Sport Med. 2001;29(1):15–17.
6. 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 Sport Med. 2016;44(3):723–728.
7. 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 Sport Med. 2017 April:363546517699832. DOI:10.1177/0363546517699832
8. Dodson CC, Slenker N, Cohen SB, et al. Ulnar collateral ligament injuries of the elbow in professional football quarterbacks. J Shoulder Elb Surg. 2010;19(8):1276–1280.
9. Fleisig GS, Andrews JR, Dillman CJ, et al. Kinetics of baseball pitching with implications about injury mechanisms. Am J Sport Med. 1995;23(2):233–239.
10. Conway JE, Jobe FW, Glousman RE, et al. Medial instability of the elbow in throwing athletes. JBJS Am. 1992;74(1):67–83.
11. Azar FM, Andrews JR, Wilk KE, et al. Operative treatment of ulnar collateral ligament injuries of the elbow in athletes. Am J Sport Med. 2000;28(1):16–23.
12. McFarland EG, Johansen JA, Freehill MT, et al. Petersen SA. Physical examination of the shoulder and elbow in the baseball player. In: Dines JM, Altchek DW, Andrews J, et al., eds. Sports medicine of baseball. Philadelphia, PA: Lippincott Williams & Wilkins; 2012. p. 53.
13. Patel RM, Lynch TS, Amin NH, et al. The thrower's elbow. Orthop Clin N Amer. 2014;45:355–376.
14. Ellenbecker TS, Mattalino AJ, Elam EA, et al. Medial elbow joint laxity in professional baseball pitchers. A bilateral comparison using stress radiography. Am J Sports Med. 1998;26(3):420–424.
15. O'Driscoll SWM, Lawton RL, Smith AM. The "moving valgus stress test" for medial collateral ligament tears of the elbow. Am J Sport Med. 2005;33(2):231–239.
16. Salvo JP, Rizio L 3rd, Zvijac JE, et al. Avulsion fracture of the ulnar sublime tubercle in overhead throwing athletes. Am J Sports Med. 2002;30(3):426–431.
17. Mulligan SA, Schwartz ML, Broussard MF, et al. Heterotopic calcification and tears of the ulnar collateral ligament: radiographic and MR imaging findings. AJR Am J Roentgenol. 2000;175(4):1099–1102.
18. Dugas JR. Valgus extension overload: diagnosis and treatment. Clin Sports Med. 2010;29(4):645–654.
19. Cain EL, Andrews JR, Dugas JR, et al. Outcome of ulnar collateral ligament reconstruction of the elbow in 1281 athletes. Am J Sport Med. 2010;38:2426–2434.
20. Wright RW, Steger-May K, Klein SE. Radiographic findings in the shoulder and elbow of major league baseball pitchers. Am J Sport Med. 2007;35:1839–1843.
21. Rijke AM, Goitz HT, McCue FC, et al. Stress radiography of the medial elbow ligaments. Radiology. 1994;191(1):213–216.
22. Timmerman LA, Schwartz ML, Andrews JR. Preoperative evaluation of the ulnar collateral ligament by magnetic resonance imaging and computed tomography arthrography: evaluation in 25 baseball players with surgical confirmation. Am J Sport Med. 1994;22:26–32.
23. Roedl JB, Gonzalez FM, Zoga AC, et al. Potential utility of a combined approach with US and MR arthrography to image medial elbow pain in baseball players. Radiology. 2016;279(3):827–837.
24. Dugas JR, Ostrander RV, Cain EL, et al. Anatomy of the anterior bundle of the ulnar collateral ligament. J Shoulder Elb Surg. 2007;16(5):657–660.
25. 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(3):e422–6.
26. Nassab PF, Schickendantz MS. Evaluation and treatment of medial ulnar collateral ligament injuries in the throwing athlete. Sports Med Arthrosc. 2006;14(4):221–231.
27. Oyama S, Yu B, Blackburn JT, et al. Improper trunk rotation sequence is associated with increased maximal shoulder external rotation angle and shoulder joint force in high school baseball pitchers. Am J Sports Med. 2014;42(9):2089–2094.
28. Davis JT, Limpisvasti O, Fluhme D, et al. The effect of pitching biomechanics on the upper extremity in youth and adolescent baseball pitchers. Am J Sport Med. 2009;37(8):1484–1491.
29. 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(9):2075–2081.
30. Garrison JC, Cole MA, Conway JE, et al. Shoulder range of motion deficits in baseball players with an ulnar collateral ligament tear. Am J Sports Med. 2012;40(11):2597–2603.
31. Whiteside D, Martini DN, Lepley AS, et al. Predictors of ulnar collateral ligament reconstruction in major league baseball pitchers. Am J Sports Med. 2016;44(9):2202–2209.
32. Chalmers PN, Erickson BJ, Ball B, et al. Fastball pitch velocity helps predict ulnar collateral ligament reconstruction in major league baseball pitchers. Am J Sports Med. 2016;44(8):2130–2135.
33. Keller RA, Marshall NE, Guest J-M, et al. Major league baseball pitch velocity and pitch type associated with risk of ulnar collateral ligament injury. J Shoulder Elb Surg. 2016;25(4):671–675.
34. 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(6):905–912.
35. 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(7):1689–1694.
36. 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 (Belle Mead NJ). 2016;45(5):296–300.