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Medial elbow stability assessment after ultrasound-guided ulnar collateral ligament transection in a cadaveric model: ultrasound versus stress radiography

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Background: The ulnar collateral ligament (UCL), consisting of 3 bundles, is the primary medial restraint in the elbow. Recent research has demonstrated that ultrasound is an effective modality to evaluate the medial elbow, whereas stress radiography is standard practice in the measurement of medial elbow laxity. This study (1) compared dynamic ultrasound (US_D) with stress radiography in the evaluation of UCL insufficiency and (2) further evaluated the contribution of the anterior bundle of the UCL to medial elbow stability.

Methods: Stress radiographs and US_D were used to obtain coronal plane measurements of the medial joint space of 16 cadaveric elbows before and after US_D-guided isolated transection of the anterior bundle of the UCL. Measurements were performed with and without a valgus stress applied to the elbows, and gapping of the ulnohumeral joint space was documented.

Results: Transection of the anterior bundle of the UCL resulted in 1.5 mm and 1.7 mm of additional gapping in the ulnohumeral joint as measured with stress radiographs and US_D, respectively. No differences were recorded in the ulnohumeral gapping measurements between stress radiography and US_D.

Conclusions: The lack of difference between measurements reveals US_D is as reliable as stress radiography in evaluating the medial ulnohumeral joint space and continuity of the UCL while eliminating radiation exposure and minimizing cost of the diagnostic examination. The increase in ulnohumeral gapping with isolated transection of the anterior bundle of the UCL demonstrates its significant contribution to medial elbow stability.

Level of evidence: Basic Science Study; Anatomy; Imaging

Keywords: Elbow x-ray; valgus stress; elbow imaging; ulnar collateral ligament injury; elbow; medial collateral ligament; dynamic ultrasound

The ulnar collateral ligament (UCL), on the medial aspect of the elbow, consists of 3 bundles: an anterior bundle, a posterior bundle, and a transverse oblique bundle.[22,23] The anterior bundle originates on the medial epicondyle of the humerus

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and inserts on the sublime tubercle of the ulna. The posterior bundle is a less defined thickening of the posterior elbow capsule. The oblique bundle, also termed the transverse ligament, is variably present and has little known role in elbow stability. The anterior bundle clinically is the most important bundle of the UCL because it is the primary restraint to valgus stress from 30° to 120° of elbow flexion and is susceptible to injury in the overhead athlete.[1,5,7] Injuries to the UCL lead to laxity of the medial elbow joint, with resultant pain and a decrease in performance potentially resulting in a career-threatening injury.[5]

The incidence of UCL injuries and resultant operations are common, with an average overall incidence of 1.12 per 10,000 athlete exposures and 85% of injuries being attributed to throwing.[14] A survey of Division I collegiate baseball programs revealed approximately 2.5% of eligible collegiate baseball players underwent surgery for an injured UCL in a single season.[28] A survey of professional baseball players revealed that 25% of Major League Baseball pitchers and 15% of Minor League Baseball pitchers had a history of UCL reconstruction.[12] Although UCL injuries are common in baseball players, injury to the UCL has also been reported in javelin throwers,[19,32] arm wrestlers,[31] and collegiate wrestlers.[31,33] Injuries to the UCL in the overhead athlete are attributed to multiple causes, including modifiable or preventable ones such as overuse, early specialization, and playing when fatigued.[11,25,29]

Complete recovery after surgery to repair or reconstruct the UCL takes months (return to competitive throwing in 9-12 months) and nonoperative treatment, if unsuccessful, further delays return to play.[5] Successful treatment requires a precise and accurate diagnosis of the UCL injury, which is achieved with a detailed and specific history, a complete physical examination, and multimodal imaging studies.

Available imaging techniques for evaluating the UCL include static and dynamic methods. Static methods include magnetic resonance imaging with or without an arthrogram.[16] Magnetic resonance arthrography enhanced with intra-articular gadolinium has been shown to improve the diagnosis of partial undersurface tears and small full-thickness perforations.[18] However, because of its cost, magnetic resonance arthrography is not always available as an imaging technique to diagnose a UCL injury. Plain radiographs with contralateral elbow views are routinely obtained to evaluate the patient with medial elbow pain. Radiographs may demonstrate widening of the medial joint space, heterotopic ossification, or bone ossicles along the expected course of the ligament, suggesting injury.[17]

Dynamic imaging methods, such as stress radiography (XR) and dynamic ultrasound (US_D), allow for a more realistic representation of medial elbow laxity as seen during activity.[5,6] XR remains a reference-standard imaging tool for evaluating medial elbow pain and laxity. XR allows for the measurement of medial joint space widening compared with the contralateral elbow.[15,27] A gap on the injured elbow of more than 0.5 mm compared with the contralateral elbow suggests a UCL injury.[27] Recently, the use of US_D has increased for medial elbow assessment.[4,10,24]

To our knowledge, no studies have compared XR and US_D in UCL injured elbows. There are also no prior cadaveric sectioning studies that have sectioned only the anterior bundle of the UCL, while preserving the other medial structures, to further evaluate its contribution to medial elbow stability. Therefore, the purpose of this study was to (1) compare US_D with XR in the evaluation of medial elbow laxity and due to UCL insufficiency and (2) further evaluate the contribution of the anterior bundle of the UCL to medial elbow stability, specifically with the remainder of the medial elbow soft tissue support structures left intact.

Materials and methods

Specimens

The study evaluated 8 paired (16 total), fresh frozen cadaveric upper extremity specimens, extending from the first rib to the finger tips, based on an a priori power analysis calculation (2 tailed, $1 - \beta = 0.80$ and $\alpha = 0.05$) to detect a significant difference between 2 imaging modalities, US_D and XR. The specimens were stored at −20°C and thawed to room temperature before use. The donors were a mean age of 77.0 years (range, 68-85 years) at the time of death, and arm dominance was not available when the specimens were acquired.

Procedures

Static coronal plane measurements of the medial joint space of the elbow were taken with XR and US_D. Non-XRs were taken using an OEC 9800 Plus Mobile C-arm (GE OEC Medical Systems, Inc., Salt Lake City, UT, USA) in accordance with methods previously published by Bruce et al.[6] The medial joint space distance was measured by finding the most distal point of the medial trochlea and measuring the vertical distance across the joint to the ulnar coronoid (Fig. 1, *A*).

Nonstress US_D measurements were performed using a multifrequency 13-MHz linear-array transducer and standard acoustic coupling gel (SonoSite X-Porte; FUJIFILM SonoSite, Inc., Bothell, WA, USA). The probe was oriented along the long axis of the UCL. The trochlea of the humerus and the sublime tubercle of the ulna were identified as hyperechoic peaks with acoustic shadowing on either side of the ulnohumeral joint.[9] Ulnohumeral joint gapping measurements were taken as the distance between the 2 hyperechoic peaks as previously described by Ciccotti et al.[9]

A valgus stress (15-daN) was then applied using a Telos SE 2000 stress device (METAX GmbH, Hungen, Germany) with the elbows in neutral rotation and 30° of flexion. This angle was chosen to remain consistent with prior stress elbow studies in the literature.[6,9,10] XR and US_D measurements were repeated while under valgus stress. The valgus stress opening for each imaging modality was calculated by subtracting the joint space distance for the nonstress (NS) view from the stress (ST) view (ST − NS = stress opening).

The anterior bundle of the UCL was then transected while preserving the other medial soft tissue restraints (musculotendinous, ligamentous, and capsular structures) using US_D guidance by a physician with a Registered in Musculoskeletal sonography certification

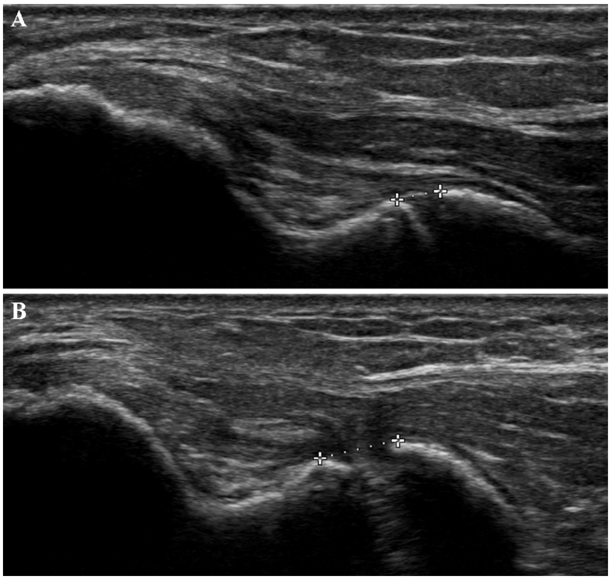

Figure 1 Ultrasound images of the medial elbow demonstrate measurement of ulnohumeral joint gapping. Measurements were taken using the "peak-to-peak" method measuring from the peak of the trochlea of the humerus (*left cross*) to the peak of the sublime tubercle (*right cross*). This distance between these 2 points is measured **(A)** at rest and **(B)** with valgus stress on the elbow with an intact ulnar collateral ligament and ulnar collateral ligament with transection of the anterior bundle.

(RMSK). To create an isolated anterior bundle transection, an #11 blade was inserted percutaneously, precisely longitudinal to all other medial structures until the location of transection at the ulnohumeral joint line, at which point it was turned transversely to cut only the anterior bundle of the ligament. It was then turned back 90° and taken back out the same path, leaving all other structures intact.

After transection of the anterior bundle of the UCL, the elbows were again stressed in the Telos device as previously described. XR and US_D were performed to measure gapping at the medial joint line of the transected specimens (Fig. 1, *B*). The valgus stress opening of the cut specimens for each imaging modality was calculated by subtracting the joint distance for the NS view from the cut view (cut – NS = cut opening). Furthermore, the difference between the intact stress view and the cut stress view was calculated by subtracting the joint distance of the valgus stress view of the intact specimen from the valgus stress view of the cut specimen (cut – ST = UCL transection stress difference). The specimens were then dissected out to confirm sectioning of the anterior bundle of the ulnar collateral ligament only and to confirm that the other stabilizing structures were still intact. Photographs were taken to document findings.

Statistical analysis

Before the analysis was conducted, the assumption of normally distributed measures was examined. Data were checked for the assumption of normality using the Shapiro-Wilk test indicating nonnormality of data ($P < .05$), and skew and kurtosis scores were observed for exceeding the maximum allowable values for a *t* test (ie, skew <|2.0| and kurtosis <|9.0|).[26] Data for NS, ST, and Cut values had a normal distribution and were evaluated using paired-samples *t* tests. Separate nonparametric Mann-Whitney *U* tests were conducted to evaluate differences between XR and US_D measures among stress opening (ST – NS), cut opening (cut – NS), and UCL transection stress difference (cut – ST) measurements. Statistical significance was set a priori at $P < .05$. All statistical analyses were performed using SPSS 22.0 software (IBM, Armonk, NY, USA).

Table I Results of ulnohumeral joint space measurements between radiographs and dynamic ultrasound in a nonstressed, stressed, and cut state

Measurement	Radiograph	Ultrasound
	Mean ± SD, mm	Mean ± SD, mm
Nonstress	3.2 ± 1.0	5.4 ± 1.9*
Stress	4.8 ± 1.6	7.0 ± 2.0*
Cut	6.3 ± 1.5	8.7 ± 2.8*
Stress opening (ST – NS)	1.6 ± 1.3	1.6 ± 0.8
Cut opening (cut – NS)	3.1 ± 1.8	3.3 ± 2.2
UCL transection stress difference (cut – ST)	1.5 ± 2.1	1.7 ± 2.1

SD, standard deviation, *ST*, stress; *NS*, nonstress; *UCL* ulnar collateral ligament.

* Indicates a significant difference ($P < .05$) between radiography and dynamic ultrasound measurements. The stressed and cut measurement represents a valgus load (15-daN) created by the Telos stress device (METAX GmbH, Hungen, Germany) with an intact and transected anterior bundle of the UCL, respectively.

Results

Means and standard deviations of the XR and US measurements for NS, ST, Cut, stress opening, cut opening, and UCL transection stress difference are presented in Table I. Significant differences were observed between XR and US_D in NS ($t_{15} = -5.90$, $P < .001$), ST ($t_{15} = -4.47$, $P < .001$), and cut ($t_{15} = -3.15$, $P = .007$). There was no difference between the XR and US_D measurements in stress opening ($U = 108.0$, $P = .451$), in which the average stress opening was 1.6 mm when using both imaging modalities. There was no difference in cut opening ($U = 85.0$, $P = .105$), where the average cut opening was 3.1 mm in XR and 3.3 mm in US_D. Furthermore, there was no difference between XR and US_D in UCL transection stress difference ($U = 94.0$, $P = .200$), where the average difference was 1.5 mm in XR and 1.7 mm in US_D.

Discussion

Despite advances in prevention and treatment of elbow injuries in throwing athletes, the incidence and disability due to these injuries continues to rise.[11,29] Surgical treatments have proven to be reliable over time, but the decision to operate or not operate on an injured athlete remains difficult. Precise evaluation of the structural integrity of the UCL ligament is central to the process. XR and US_D have both been successfully used to evaluate the UCL, although no studies to date have directly compared the 2 imaging methods.[2-4,6,10,15,21] Consequently, the results of this study indicate that XR and US_D are equally effective in evaluating the medial elbow joint space and injury to the UCL.

XR has been proven reliable in measuring the ulnohumeral joint space and diagnosing tears of the UCL; however, this technique does not provide a direct assessment of the ligament itself.[27] In individuals without a history of elbow trauma or instability and who are not overhead athletes, ulnohumeral gapping, as measured by valgus XR, is expected to be equal between the dominant and nondominant elbows.[21] In throwers, however, an increase in the amount of ulnohumeral gapping of the dominant arm may be considered adaptive and normal.[6,15] In their study of 40 asymptomatic professional pitchers, Ellenbecker et al[15] found the medial joint space of the dominant elbow opens an average of 0.32 mm more on the stress view compared with the nondominant elbow (1.20 and 0.88 mm, respectively).

Establishing a cutoff point of laxity on XR in the diagnosis of UCL tears is variable, because laxity due to accommodation from valgus forces related to throwing is expected.[8,15] Rijke et al[27] evaluated 42 athletes with suspected UCL tears and found joint space widening of more than 0.5 mm compared with the unaffected side was diagnostic for complete or high-grade partial tears of the UCL, and those with a gapping of less than 0.5 mm were found to have normal ligaments or partial UCL tears that could be managed conservatively. Similarly, Bruce et al[6] showed that 0.6 mm of gapping can be expected with XR in throwers with complete UCL tears as determined through magnetic resonance imaging findings. This differed from previous reports of 2 to 3 mm of gapping on XR with manual stressing.[1,13,19,30] The difference in these findings is postulated to be related to the use of a standardized valgus stress device used.

Our results indicate that complete transection of the UCL in a cadaveric model results in 1.5 mm of additional ulnohumeral gapping as measured by XR (UCL transection stress difference). This more closely represents the contribution of the anterior bundle to medial elbow stability and resembles in vivo changes seen in the injured state due to dynamic stability provided by the other medial structures, specifically the flexor pronator mass.

Our results reveal no significant differences between XR and US_D when evaluating the ulnohumeral joint, indicating either method can be used as a reliable imaging tool for the assessment of the UCL. US provides an efficient, low-cost, and noninvasive alternative that is free of radiation. Perhaps even more importantly, US can provide a dynamic, functional assessment of the soft tissue stabilizers of the medial elbow, specifically the anterior bundle of the UCL, with and without applied loads.[2,3,9,20] US_D also allows the examiner to assess whether the addition of stress to the elbow reproduces the pain experienced by the patient during activity, further expanding the clinical examination. Our results indicate a stress opening difference (ST – NS) of 1.6 mm, whereas Bica et al[4] observed a similar but slightly smaller stress opening difference of 1.3 mm in the dominant arm of 18 healthy pitchers, which may be explained by the contribution of dynamic stabilizers or guarding in a healthy participant that is not observed in a cadaveric model.

The contribution of the anterior band of the UCL to medial elbow valgus stability was further evaluated in this study. The study published by Ciccotti et al[9] in 2014 demonstrated the relative contributions of medial elbow stabilizers in a cadaveric model using sequential sectioning. They used US_D to quantify the contributions of each anatomic portion of the UCL and the flexor-pronator muscle mass to medial elbow stability. Using 2 separate sectioning sequences, they demonstrated discreet changes in gapping with the sectioning of each medial elbow soft tissue stabilizing structure. They showed that release of the anterior bundle of the UCL led to the greatest increase in gapping. Specifically, they found that sectioning the complete anterior bundle of the UCL led to medial ulnohumeral gapping of 3.4 mm, whereas the sum of the release of all other structures in the study was less than 1.4 mm. This led the authors to conclude that any gapping detected on stress US of ≥1.4 mm is only seen with injuries to the anterior bundle of the UCL.[9]

The UCL transection stress difference (cut – ST) of 1.5 mm and 1.7 mm, as measured using XR and US_D, respectively, reflects injury to the anterior bundle of the UCL and is similar to what is seen in clinical studies of XRs as previously reported.[6,9,16,27] The presence of a complete soft tissue sleeve and tension in the musculature would most likely account for the small difference between our cadaveric model and the previously reported clinical studies.

The current study has several limitations. US_D is user-dependent and requires an experienced ultrasonographer. The US_D evaluations in our study were performed by an experienced musculoskeletal radiologist with more than 15 years of experience and who routinely performs studies on high-level athletes. Previous literature has documented the accuracy of using US_D to measure ulnohumeral joint gapping with a precision of less than 0.5 mm, which may still induce some error of measurement.[4]

Our cadavers were a mean age of 77 years (range, 69-85 years). Although age can introduce variables, such as degenerative changes with joint space narrowing, bone spurs, or baseline tears in the ligament, no gross tears, partial or complete, were seen during the presectioning evaluation of the medial ligaments.

Conclusion

There were no significant differences between XR and US_D in the evaluation of medial elbow laxity in this cadaveric study. These findings support the use of US_D as a preferred method of evaluation of medial elbow instability in the throwing athlete. US_D gives a fast, comprehensive evaluation of the UCL in both static and dynamic states while minimizing cost and eliminating radiation exposure to the patient. Isolated sectioning of the anterior bundle of the UCL resulted in 1.7 mm of increased medial laxity, indicating its significant contribution to medial elbow stability.

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References

1. Ahmad CS, ElAttrache NS. Elbow valgus instability in the throwing athlete. J Am Acad Orthop Surg 2006;14:693-700.
2. Atanda A Jr, Buckley PS, Hammoud S, Cohen SB, Nazarian LN, Ciccotti MG. 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. http://dx.doi.org/10.1177/0363546515605042
3. Atanda A Jr, Averill LW, Wallace M, Niiler TA, Nazarian LN, Ciccotti MG. Factors related to increased ulnar collateral ligament thickness on stress sonography of the elbow in asymptomatic youth and adolescent baseball pitchers. Am J Sports Med 2016;44:3179-87. http://dx.doi.org/10.1177/0363546516661010
4. Bica D, Armen J, Kulas AS, Youngs K, Womack Z. Reliability and precision of stress sonography of the ulnar collateral ligament. J Ultrasound Med 2015;34:371-6. http://dx.doi.org/10.7863/ultra.34.3.371
5. Bruce JR, Andrews JR. Ulnar collateral ligament injuries in the throwing athlete. J Am Acad Orthop Surg 2014;22:315-25. http://dx.doi.org/10.5435/JAAOS-22-05-315
6. Bruce JR, Hess R, Joyner P, Andrews JR. How much valgus instability can be expected with ulnar collateral ligament (UCL) injuries? A review of 273 baseball players with UCL injuries. J Shoulder Elbow Surg 2014;23:1521-6. http://dx.doi.org/10.1016/j.jse.2014.05.015
7. Callaway GH, Field LD, Deng XH, Torzilli PA, O'Brien SJ, Altchek DW, et al. Biomechanical evaluation of the medial collateral ligament of the elbow. J Bone Joint Surg Am 1997;79:1223-31.
8. Chen FS, Rokito AS, Jobe FW. Medial elbow problems in the overhead-throwing athlete. J Am Acad Orthop Surg 2001;9:99-113.
9. Ciccotti MC, Hammoud S, Dodson CC, Cohen SB, Nazarian LN, Ciccotti MG. Stress ultrasound evaluation of medial elbow instability in a cadaveric model. Am J Sports Med 2014;42:2463-9. http://dx.doi.org/10.1177/0363546514542805
10. Ciccotti MG, Atanda A Jr, Nazarian LN, Dodson CC, Holmes L, Cohen SB. 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. http://dx.doi.org/10.1177/0363546513516592
11. Conte S, Camp CL, Dines JS. Injury trends in Major League Baseball over 18 seasons: 1998-2015. Am J Orthop (Belle Mead NJ) 2016;45:116-23.
12. Conte SA, Fleisig GS, Dines JS, Wilk KE, Aune KT, Patterson-Flynn N, et al. Prevalence of ulnar collateral ligament surgery in professional baseball players. Am J Sports Med 2015;43:1764-9. http://dx.doi.org/10.1177/0363546515580792
13. Conway JE, Jobe FW, Glousman RE, Pink M. Medial instability of the elbow in throwing athletes. Treatment by repair or reconstruction of the ulnar collateral ligament. J Bone Joint Surg Am 1992;74:67-83.
14. 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. http://dx.doi.org/10.1177/0363546518773314
15. Ellenbecker TS, Mattalino AJ, Elam EA, Caplinger RA. Medial elbow joint laxity in professional baseball pitchers. A bilateral comparison using stress radiography. Am J Sports Med 1998;26:420-4.
16. Eygendaal D, Heijboer MP, Obermann WR, Rozing PM. Medial instability of the elbow: findings on valgus load radiography and MRI in 16 athletes. Acta Orthop Scand 2000;71:480-3.
17. Gore RM, Rogers LF, Bowerman J, Suker J, Compere CL. Osseous manifestations of elbow stress associated with sports activities. AJR Am J Roentgenol 1980;134:971-7.
18. Hill NB Jr, Bucchieri JS, Shon F, Miller TT, Rosenwasser MP. Magnetic resonance imaging of injury to the medial collateral ligament of the elbow: a cadaver model. J Shoulder Elbow Surg 2000;9:418-22.
19. Jobe FW, Stark H, Lombardo SJ. Reconstruction of the ulnar collateral ligament in athletes. J Bone Joint Surg Am 1986;68:1158-63.
20. Kim NR, Moon SG, Park JY, Choi JW, Oh KS. Stress ultrasound in baseball players with ulnar collateral ligament injuries: additional value for predicting rehabilitation outcome. J Shoulder Elbow Surg 2017;26:815-23. http://dx.doi.org/10.1016/j.jse.2016.12.075
21. Lee GA, Katz SD, Lazarus MD. Elbow valgus stress radiography in an uninjured population. Am J Sports Med 1998;26:425-7.
22. Morrey BF, An KN. Articular and ligamentous contributions to the stability of the elbow joint. Am J Sports Med 1983;11:315-9.
23. Morrey BF, An KN. Functional anatomy of the ligaments of the elbow. Clin Orthop Relat Res 1985;(11):84-90.
24. Nazarian LN, McShane JM, Ciccotti MG, O'Kane PL, Harwood MI. Dynamic US of the anterior band of the ulnar collateral ligament of the elbow in asymptomatic major league baseball pitchers. Radiology 2003;227:149-54. http://dx.doi.org/10.1148/radiol.2271020288
25. 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. http://dx.doi.org/10.1177/0363546503262166
26. Posten HO. Robustness of the two-sample t-test. In: Rasch D, Tiku ML, editors. Robustness of statistical methods and nonparametric statistics. Dordrecht: Springer Netherlands; 1984. p. 92-9 ISBN 978-94-009-6528-7.
27. Rijke AM, Goitz HT, McCue FC, Andrews JR, Berr SS. Stress radiography of the medial elbow ligaments. Radiology 1994;191:213-6.
28. Rothermich MA, Conte SA, Aune KT, Fleisig GS, Cain EL Jr, Dugas JR. Incidence of elbow ulnar collateral ligament surgery in collegiate baseball players. Orthop J Sports Med 2018;6:2325967118764657. http://dx.doi.org/10.1177/2325967118764657
29. Saper MG, Pierpoint LA, Liu W, Comstock RD, Polousky JD, Andrews JR. Epidemiology of shoulder and elbow injuries among united states high school baseball players: school years 2005-2006 through 2014-2015. Am J Sports Med 2018;46:37-43. http://dx.doi.org/10.1177/0363546517734172
30. Thompson WH, Jobe FW, Yocum LA, Pink MM. Ulnar collateral ligament reconstruction in athletes: muscle-splitting approach without transposition of the ulnar nerve. J Shoulder Elbow Surg 2001;10:152-7. http://dx.doi.org/10.1067/mse.2001.112881
31. Tullos HS, Erwin WD, Woods GW, Wukasch DC, Cooley DA, King JW. Unusual lesions of the pitching arm. Clin Orthop Relat Res 1972;(88):169-82.
32. Waris W. Elbow injuries of javelin-throwers. Acta Chir Scand 1946;93:563-75.
33. Yocum LA. The diagnosis and nonoperative treatment of elbow problems in the athlete. Clin Sports Med 1989;8:439-51.