Do Professional Baseball Players With a Higher Valgus Carrying Angle Have an Increased Risk of Shoulder and Elbow Injuries?

Brandon J. Erickson,*† MD, Peter N. Chalmers,‡ MD, John Zajac,§ ATC, Terrance Sgroi,‖ PT, Jonathan James Eno,¶ MD, David W. Altchek,‖ MD, Joshua S. Dines,‖ MD, and Struan H. Coleman,‖ MD

Investigation performed at the Hospital for Special Surgery, New York, New York, USA

Background: There are many risk factors for shoulder and elbow injuries in professional baseball pitchers. The elbow carrying angle has not been studied as a potential risk factor.

Purpose/Hypothesis: The aim of this study was to determine whether elbow carrying angle is a risk factor for shoulder or elbow injuries in professional baseball pitchers. We hypothesized that pitchers with a higher elbow carrying angle would be less likely to sustain an injury during the season than pitchers with a lower elbow carrying angle.

Study Design: Cohort study; Level of evidence, 2.

Methods: All professional pitchers for a single baseball club during the 2018 season had the carrying angle of both elbows measured at spring training by a single examiner. The pitchers were followed prospectively throughout the season. Shoulder and elbow injuries were recorded prospectively.

Results: A total of 52 pitchers (21 [40%] Major League Baseball and 31 [60%] Minor League Baseball) were included. During the season, 23 (44%) pitchers became injured. The mean carrying angle in the throwing arm was 12.5° ± 4.2° versus 9.9° ± 2.8° in the nonthrowing arm ($P < .001$). Comparing the injured and noninjured groups, there were no differences in level of play ($P = .870$), throwing hand dominance ($P = .683$), batting hand dominance ($P = .554$), throwing-side carrying angle ($P = .373$), nonthrowing-side carrying angle ($P = .773$), or side-to-side difference in carrying angle ($P = .481$).

Conclusion: The elbow carrying angle was not associated with an injury risk during a single season in professional baseball pitchers.

Keywords: Major League Baseball (MLB); elbow; injury prevention; carrying angle; pitcher; shoulder

Shoulder and elbow injury rates in baseball pitchers of all levels have been increasing over the past decade.[4,15,17] While several risk factors for an injury have been identified and prevention programs implemented, these injury rates have yet to level off. Currently identified risk factors for an injury in baseball pitchers include high pitch counts, pitch velocity, overall pitching workload, pitching year round, pitching while fatigued, geographic location, loss of shoulder motion (including forward flexion, internal rotation, and total arc of motion), loss of hip motion, elbow torque, and others.[#] Unfortunately, as injury rates continue to rise, there are likely other risk factors that have not been identified.

The elbow joint is a complex hinge joint that is made up of 3 distinct articulations.[33] The valgus carrying angle, the angle between a line drawn down the axis of the arm and down the axis of the forearm, is between 11° and 16° (higher in females than males).[11] This allows the forearm and wrist to clear the hips during gait. Baseball pitchers generate more valgus stress on the medial elbow during the pitching motion than the ulnar collateral ligament (UCL) can withstand alone.[29-31,35] Bony and other soft tissue/muscular restraints, specifically the wrist flexors and forearm pronators, help to protect

The Orthopaedic Journal of Sports Medicine, 7(8), 2325967119866734
DOI: 10.1177/2325967119866734

[#]References 1-3, 7-9, 12, 14, 16, 21-24, 26-28, 36, 37.

the UCL.[18,34,35] Recent evidence has shown that contraction of the wrist and finger flexors helps to compress the medial side of the elbow when valgus stress is applied.[32] A smaller elbow carrying angle may create an obligate increase in torque across the UCL for the same ball velocity, but this factor has not been studied as it relates to the injury risk in baseball pitchers, specifically professional baseball pitchers.

The purpose of this study was to determine if a professional baseball pitcher's elbow valgus carrying angle is a risk factor for injuries. A secondary aim was to compare side-to-side differences in the elbow carrying angle between a pitcher's throwing and nonthrowing elbows to determine if a difference existed. We hypothesized that pitchers with a higher valgus carrying angle would be less likely to sustain an injury during the season than pitchers with a lower valgus carrying angle. We also hypothesized that the carrying angle would be greater in the throwing elbow than the nonthrowing elbow. The thought process behind the hypothesis was that the elbow has to achieve a certain amount of valgus to generate enough torque and energy to throw a baseball at high speeds. Hence, if the player is starting with more elbow valgus, he has less of a distance to go to achieve the appropriate valgus and therefore would stress his ligament to a lesser degree.

METHODS

Institutional review board approval was obtained before initiating this study. All professional baseball pitchers who played for a single baseball club at the start of the 2018 season and were available for an examination at spring training were eligible for inclusion. Inclusion criteria were healthy male (currently not injured) professional (Major League Baseball [MLB] and Minor League Baseball [MiLB]) pitchers. Players were excluded if they were injured at the time that the measurements were taken or if they refused to participate. Participation was voluntary. At spring training, on 2 consecutive days, the elbow valgus carrying angle was measured in both the dominant and nondominant elbows of all included pitchers by 1 author (B.J.E.). No pitcher refused to participate. The examiner was not blinded to arm dominance.

The measurements were taken with the players supine, the elbow in full extension, and the hand completely supinated. As has been previously described, when measuring the carrying angle (Figure 1), the goniometer was oriented such that the center of the instrument was positioned on the cross line of the bicep's tendon and the interepicondyle axis.[10] The distal arm of the goniometer was aligned with the center of the wrist, and the proximal arm was oriented with the center of the arm. All pitchers were measured in the same position, with the same equipment, by the same examiner (B.J.E.).[10] Players were evaluated prospectively throughout the season, and injury data were recorded. For the purpose of this study, an injury was defined as any condition that placed the pitcher on the disabled list, causing him to miss time. Upper extremity (shoulder, elbow, forearm, etc) injuries were recorded and documented for all players.

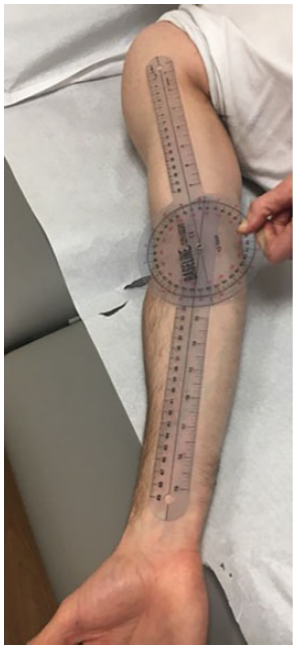

Figure 1. The goniometer and setup for the measurements. The hand is completely supinated, the elbow is in full extension, the distal limb of the goniometer is centered on the wrist, and the proximal end of the goniometer is centered on the humeral shaft.

*Address correspondence to Brandon J. Erickson, MD, Department of Orthopaedic Surgery, Rothman Orthopaedic Institute, 176 3rd Avenue, New York, NY 10003, USA (email: brandon.erickson@rothmanortho.com).
†Department of Orthopaedic Surgery, Rothman Orthopaedic Institute, New York, New York, USA.
‡Department of Orthopaedics, University of Utah, Salt Lake City, Utah, USA.
§Department of Physical Medicine and Rehabilitation, Mayo Clinic, Scottsdale, Arizona, USA.
‖Sports Medicine and Shoulder Service, Hospital for Special Surgery, New York, New York, USA.
¶Department of Sports Medicine, Kaiser Permanente San Francisco, San Francisco, California, USA.

One or more of the authors has declared the following potential conflict of interest or source of funding: B.J.E. has received research support from DePuy and Smith & Nephew. P.N.C. has received educational support from Tornier. J.J.E. has received educational support from Smith & Nephew. D.W.A. has received educational support from Arthrex and Stryker. J.S.D. has received consulting fees from Arthrex, Linvatec, DePuy, Merck Sharp & Dohme, Trice, and Wright Medical; speaking fees from Arthrex; research support from Arthrex; royalties from Wolters Kluwer Health–Lippincott Williams & Wilkins; and hospitality payments from Horizon Pharma. S.H.C. has received consulting fees from Stryker/Pivot Medical, speaking fees from Smith & Nephew, and royalties from Blue Belt Technologies and has stock/stock options in Blue Belt Technologies and CyMedica Orthopedics. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from the Hospital for Special Surgery Institutional Review Board (No. 2015-922).

Statistical Analysis

Descriptive statistics were calculated and examined for spurious values. Continuous variables were evaluated for normality using the Kolmogorov-Smirnov test. Based on the results of this test, nonparametric tests were used. Categorical variables were compared between the injured and noninjured groups using the chi-square or Fisher exact tests, as appropriate depending on subsample sizes. Continuous variables were compared between the injured and noninjured groups using the Mann-Whitney *U* test. To compare throwing and nonthrowing arms, we used the related-samples Wilcoxon signed-rank test. An additional post hoc power analysis was conducted using this test based on the observed effect size. *P* values $<.05$ were considered significant. All analyses were conducted in Excel 16 (Microsoft), SPSS 25 (IBM), and G*Power 3.[20]

RESULTS

A total of 52 pitchers were included, of whom 21 (40%) were MLB pitchers and 31 (60%) were MiLB pitchers. This included 42 (81%) who threw right-handed and 41 (79%) who batted right-handed. During the season, 23 (44%) sustained an upper extremity injury of the dominant arm, causing them to spend time on the disabled list. These injuries included shoulder impingement (6 pitchers, all successfully treated nonoperatively), UCL tears (5 pitchers, of whom 4 underwent UCL reconstruction [UCLR] and 1 was successfully treated nonoperatively with platelet-rich plasma and rehabilitation), proximal biceps tendinitis (5 pitchers, all successfully treated nonoperatively), labral tears (2 pitchers, both treated with surgical labral repair), elbow stiffness (2 pitchers, both successfully treated nonoperatively), forearm strain (2 pitchers, both successfully treated nonoperatively), and a symptomatic Bennett lesion (1 pitcher, treated with an injection). The mean carrying angle in the throwing arm was $12.5^\circ \pm 4.2^\circ$ and in the nonthrowing arm was $9.9^\circ \pm 2.8^\circ$, which was significantly different between arms (mean difference, 2.6 [95% CI, 1.6-3.6]; $P < .001$).

Comparing the injured and noninjured groups, there were no differences in level of play ($P = .870$), throwing hand dominance ($P = .683$), batting hand dominance ($P = .554$), throwing-side carrying angle ($P = .373$), nonthrowing-side carrying angle ($P = .773$), or side-to-side difference in carrying angle ($P = .481$) (Table 1).

A post hoc power analysis was conducted using the utilized statistical tests and observed mean values in the injured and noninjured groups for throwing-side carrying angle, which revealed an effect size of 0.26. With α set at .05 and β set at 0.8, 482 pitchers would be required to show a difference, should one exist. This group size exceeds the number of MLB pitchers.

TABLE 1
Comparison of Variables Between Injured and Noninjured Players[a]

Variable	Injured (n = 23)	Noninjured (n = 29)	*P* Value
Level of play, n (%)	9 (39)	12 (41)	.870
Throwing right handed, n (%)	18 (78)	24 (83)	.683
Batting right handed, n (%)	19 (83)	22 (76)	.554
Throwing-side carrying angle, deg	11.9 ± 4.2	13.0 ± 4.2	.373
Nonthrowing-side carrying angle, deg	9.6 ± 2.1	10.1 ± 3.3	.773
Side-to-side difference in carrying angle, deg	2.3 ± 3.8	2.8 ± 3.8	.481

[a]Data are presented as mean ± SD unless otherwise specified.

DISCUSSION

Shoulder and elbow injuries in professional baseball players have been on the rise in the past 10 years. While several studies have examined modifiable risk factors for these injuries, there have been limited data on nonmodifiable risk factors. Contrary to our hypothesis, this study found no correlation between the elbow carrying angle and the risk of shoulder or elbow injuries in professional baseball players.

There has been a recent push to identify risk factors for shoulder and elbow injuries in overhead athletes, as the rates of these injuries have continued to rise.[5,8,18] Camp et al[5] evaluated all MLB players who missed at least 1 day of play between 2011 and 2016 using the MLB Health and Injury Tracking System (HITS). They found 49,955 injuries (45,123 were non–season ending), resulting in 722,176 days out of play, 39% of which involved the upper extremity. Their study identified the scope of the issue facing MLB players. Several studies have been conducted to isolate specific risk factors for shoulder and elbow injuries in professional baseball players. Chalmers et al[8] evaluated all professional pitchers who underwent UCLR between 2007 and 2015 to determine if pitch velocity was a risk factor for UCL injuries. The authors collected data on pitch count, pitch type (fastball, curveball, etc), and pitch velocity on all MLB players and compared those pitchers who underwent UCLR with pitchers who did not require UCLR. The authors found that peak pitch velocity and mean pitch velocity were significantly higher in the pitchers who required UCLR compared with those who did not. Similar studies evaluating potential modifiable risk factors for an injury have been performed in professional as well as high school and college-aged pitchers and have found pitch count, number of innings pitched per season, pitching while fatigued, shoulder motion, hip motion, pitching complete games, and other variables to be risk factors for an injury.[6,7,13,19,21,22,36,37]

While these studies have reported modifiable risk factors, there are also several risk factors that are nonmodifiable. Pitcher age, for example, is a nonmodifiable risk factor that has been shown to increase a player's risk for sustaining a UCL tear.[8] Another nonmodifiable risk factor that has been associated with shoulder and elbow injuries in high-level baseball pitchers is pitcher height, as taller players are more likely to sustain an injury

than shorter pitchers.[8] While there are several nonmodifiable risk factors that have been associated with an injury, there are others, such as handedness, that have not been found to increase a pitcher's risk for injuries; right-handed throwers are no more likely to sustain an injury than left-handed throwers.[15] It is important to identify all possible risk factors, both modifiable and nonmodifiable, so that a pitcher can properly train and adequately prepare himself for each outing. For example, if a pitcher has several nonmodifiable risk factors for sustaining a shoulder or elbow injury, he may need more time between starts or to have reduced workloads than pitchers without any nonmodifiable risk factors so as to avoid injuries.

This study evaluated the potential nonmodifiable risk factor of a pitcher's elbow carrying angle. This valgus angle allows the arm to swing freely without hitting the leg. To generate a forceful pitch, a significant amount of stress is placed across the shoulder and elbow. The elbow experiences valgus stress of approximately 64 N·m with every pitch.[23] As the pitching motion is part of the kinetic chain, this stress can increase if the scapula is not in its proper position.[25] It is unclear if a change in the valgus carrying angle of the elbow increases, decreases, or has no effect on the stress seen by the shoulder and/or medial elbow during pitching.

We found a side-to-side difference in the valgus carrying angle between the dominant and nondominant elbows of pitchers. The increase in the valgus carrying angle of the dominant elbow could be an adaptive change secondary to lateral physis growth arrest, chronic tension on the medial elbow, wear and/or compression of radiocapitellar articular cartilage, or for other reasons. Another possible cause is a small amount of medial laxity at rest causing an apparent increase in elbow valgus, as the medial structures are slightly looser than the lateral ones from overuse. No longitudinal studies in youth pitchers have been conducted to understand when this difference in the valgus carrying angle develops, so it is difficult to determine the cause. Future longitudinal studies are necessary to follow youth pitchers from adolescence through college to evaluate the progression of the elbow carrying angle over time so as to provide a better understanding of how this variable affects pitchers.

We did not see a correlation between the elbow carrying angle and shoulder and elbow injuries in professional baseball pitchers. One possible reason for the lack of correlation is that pitchers have adapted to their anatomy. This allows them to compensate for any anatomic abnormalities during the pitch. Further studies comparing pitchers with a history of specific shoulder and elbow procedures (UCLR, labral repair, etc) to controls may be warranted. However, it may be that there is no set amount of valgus that the elbow needs to achieve to throw a baseball at a high velocity, so the amount of elbow valgus in pitchers may be arbitrary. This study was underpowered, as over 400 pitchers would have been needed to detect a difference if one existed, and this number far exceeds the number of pitchers in a single organization. Hence, a larger scale study across multiple organizations is needed to better answer this question.

Limitations

This study evaluated professional baseball pitchers for a single organization over the course of a single season. The included players were all professional athletes, and as such, these results may not be generalizable to other populations. There may be an inherent selection bias, as these athletes were all professionals and may have learned to compensate for abnormalities in their elbow valgus carrying angle. Injury history was not evaluated, as the purpose of this study was to prospectively follow pitchers over the course of a season. It is also possible that the valgus carrying angle effect may have been overwhelmed by other risk factors, and a multivariate analysis would be needed (with a large number of participants) to sort out whether the valgus carrying angle was significant. Further studies evaluating multiple baseball clubs over a longer period may be necessary to study this clinical question even further.

CONCLUSION

The elbow carrying angle was not associated with an injury risk during a single season in professional baseball pitchers.

REFERENCES

1. Anz AW, Bushnell BD, Griffin LP, Noonan TJ, Torry MR, Hawkins RJ. Correlation of torque and elbow injury in professional baseball pitchers. *Am J Sports Med*. 2010;38(7):1368-1374.
2. Axe MJ, Strube M, Osinski D, Andrews JR, Snyder-Mackler L. A speed distance-based classification system for injury prevention and research in international and domestic youth baseball players. *Int J Sports Phys Ther*. 2014;9(3):346-355.
3. Bushnell BD, Anz AW, Noonan TJ, Torry MR, Hawkins RJ. Association of maximum pitch velocity and elbow injury in professional baseball pitchers. *Am J Sports Med*. 2010;38(4):728-732.
4. Cain EL Jr, 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(12):2426-2434.
5. Camp CL, Dines JS, van der List JP, et al. Summative report on time out of play for Major and Minor League Baseball: an analysis of 49,955 injuries from 2011 through 2016. *Am J Sports Med*. 2018;46(7): 1727-1732.
6. Camp CL, Spiker AM, Zajac JM, et al. Decreased hip internal rotation increases the risk of back and abdominal muscle injuries in professional baseball players: analysis of 258 player-seasons. *J Am Acad Orthop Surg*. 2018;26(9):e198-e206.
7. Camp CL, Zajac JM, Pearson DB, et al. Decreased shoulder external rotation and flexion are greater predictors of injury than internal rotation deficits: analysis of 132 pitcher-seasons in professional baseball. *Arthroscopy*. 2017;33(9):1629-1636.
8. Chalmers PN, Erickson BJ, Ball B, Romeo AA, Verma NN. Fastball pitch velocity helps predict ulnar collateral ligament reconstruction in Major League Baseball pitchers. *Am J Sports Med*. 2016;44(8): 2130-2135.
9. Chalmers PN, Sgroi T, Riff AJ, et al. Correlates with history of injury in youth and adolescent pitchers. *Arthroscopy*. 2015;31(7):1349-1357.

10. Chapleau J, Canet F, Petit Y, Laflamme GY, Rouleau DM. Validity of goniometric elbow measurements: comparative study with a radiographic method. *Clin Orthop Relat Res*. 2011;469(11):3134-3140.
11. Chen FS, Rokito AS, Jobe FW. Medial elbow problems in the overhead-throwing athlete. *J Am Acad Orthop Surg*. 2001;9(2): 99-113.
12. Erickson BJ, Chalmers PN, Bach BR Jr, et al. Length of time between surgery and return to sport after ulnar collateral ligament reconstruction in Major League Baseball pitchers does not predict need for revision surgery. *J Shoulder Elbow Surg*. 2017;26(4):699-703.
13. Erickson BJ, Chalmers PN, Romeo AA, Ahmad CS. Relationship between pitching a complete game and spending time on the disabled list for Major League Baseball pitchers. *Orthop J Sports Med*. 2018;6(3):2325967118761354.
14. Erickson BJ, Cvetanovich GL, Bach BR Jr, Bush-Joseph CA, Verma NN, Romeo AA. Should we limit innings pitched after ulnar collateral ligament reconstruction in Major League Baseball pitchers? *Am J Sports Med*. 2016;44(9):2210-2213.
15. 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(3):536-543.
16. Erickson BJ, Harris JD, Tetreault M, Bush-Joseph C, Cohen M, Romeo AA. Is Tommy John surgery performed more frequently in Major League Baseball pitchers from warm weather areas? *Orthop J Sports Med*. 2014;2(10):2325967114553916.
17. 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(7):1770-1774.
18. Erickson BJ, Romeo AA. The ulnar collateral ligament injury: evaluation and treatment. *J Bone Joint Surg Am*. 2017;99(1):76-86.
19. Erickson BJ, Sgori T, Chalmers PN, et al. The impact of fatigue on baseball pitching mechanics in adolescent male pitchers. *Arthroscopy*. 2016;32(5):762-771.
20. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behav Res Methods*. 2009;41(4):1149-1160.
21. Fleisig GS, Andrews JR. Prevention of elbow injuries in youth baseball pitchers. *Sports Health*. 2012;4(5):419-424.
22. Fleisig GS, Andrews JR, Cutter GR, et al. Risk of serious injury for young baseball pitchers: a 10-year prospective study. *Am J Sports Med*. 2011;39(2):253-257.
23. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. *Am J Sports Med*. 1995;23(2):233-239.
24. Fortenbaugh D, Fleisig GS, Andrews JR. Baseball pitching biomechanics in relation to injury risk and performance. *Sports Health*. 2009;1(4):314-320.
25. Itami Y, Mihata T, McGarry MH, et al. Effect of increased scapular internal rotation on glenohumeral external rotation and elbow valgus load in the late cocking phase of throwing motion. *Am J Sports Med*. 2018;46(13):3182-3188.
26. Keller RA, Marshall NE, Guest JM, Okoroha KR, Jung EK, Moutzouros V. Major League Baseball pitch velocity and pitch type associated with risk of ulnar collateral ligament injury. *J Shoulder Elbow Surg*. 2016;25(4):671-675.
27. Keller RA, Mehran N, Khalil LS, Ahmad CS, ElAttrache N. Relative individual workload changes may be a risk factor for rerupture of ulnar collateral ligament reconstruction. *J Shoulder Elbow Surg*. 2017; 26(3):369-375.
28. Li X, Ma R, Zhou H, et al. Evaluation of hip internal and external rotation range of motion as an injury risk factor for hip, abdominal and groin injuries in professional baseball players. *Orthop Rev (Pavia)*. 2015;7(4):6142.
29. Loftice J, Fleisig GS, Zheng N, Andrews JR. Biomechanics of the elbow in sports. *Clin Sports Med*. 2004;23(4):519-530.
30. Morrey BF. Applied anatomy and biomechanics of the elbow joint. *Instr Course Lect*. 1986;35:59-68.
31. Pappas AM, Zawacki RM, Sullivan TJ. Biomechanics of baseball pitching: a preliminary report. *Am J Sports Med*. 1985;13(4): 216-222.
32. Pexa BS, Ryan ED, Myers JB. Medial elbow joint space increases with valgus stress and decreases when cued to perform a maximal grip contraction. *Am J Sports Med*. 2018;46(5):1114-1119.
33. Schwab GH, Bennett JB, Woods GW, Tullos HS. Biomechanics of elbow instability: the role of the medial collateral ligament. *Clin Orthop Relat Res*. 1980;146:42-52.
34. Sisto DJ, Jobe FW, Moynes DR, Antonelli DJ. An electromyographic analysis of the elbow in pitching. *Am J Sports Med*. 1987;15(3): 260-263.
35. Werner SL, Fleisig GS, Dillman CJ, Andrews JR. Biomechanics of the elbow during baseball pitching. *J Orthop Sports Phys Ther*. 1993; 17(6):274-278.
36. 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.
37. Wilk KE, Macrina LC, Fleisig GS, et al. Deficits in glenohumeral passive range of motion increase risk of shoulder injury in professional baseball pitchers: a prospective study. *Am J Sports Med*. 2015; 43(10):2379-2385.