

Preseason Neck Mobility Is Associated With Throwing-Related Shoulder and Elbow Injuries, Pain, and Disability in College Baseball Pitchers

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Background: Shoulder and elbow injuries in baseball pitchers, which can lead to significant pain and disability, have been on the rise at all levels of play for 3 decades. Despite anatomic and neurophysiological relationships, neck mobility has not been explored as a contributor to shoulder and elbow injuries in baseball pitchers.

Hypothesis: Impaired neck mobility will increase the risk of shoulder and elbow injuries in college baseball pitchers.

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

Methods: Posture, neck mobility, and shoulder passive range of motion were measured in healthy college baseball pitchers during the 2018 preseason. Time loss (days lost because of shoulder or elbow injuries) and patient-reported disability via Functional Arm Scale for Throwers (FAST) scores were used to dichotomize pitchers into injured and uninjured groups. Receiver operating characteristic curves were generated, and accuracy values and risk ratios (RRs) were calculated to assess the diagnostic utility of the physical measures. Time-to-injury analysis was conducted to assess the timing of injuries.

Results: A total of 49 pitchers (mean age, 19.92 ± 1.48 years; mean height, 187.04 ± 6.02 cm; mean weight, 89.14 ± 12.08 kg) completed the study. There were 10 pitchers (20.4%) who sustained a time-loss injury >7 days because of a shoulder or elbow injury. A Cervical Flexion-Rotation Test (CFRT) finding on the dominant side of ≤39° resulted in over 9 times the increased risk of time-loss injuries (RR, 9.38 [95% CI, 1.28-68.49]). Time-to-injury analysis demonstrated differences between the 2 groups ($\chi^2 = 7.667$; $P = .01$). Pitchers with a >39.25° finding on the CFRT played a mean 109.4 of 112 days (95% CI, 105-114) before the injury, while pitchers with ≤39.25° only played 83.6 of 112 days (95% CI, 68-99). A CFRT finding of ≤38° (RR, 3.91 [95% CI, 1.23-12.39]), cervical flexion range of motion of ≤64° (RR, 10.56 [95% CI, 1.50-74.34]), and weight of >86.9 kg (RR, 10.42 [95% CI, 1.14-213.70]) were also associated with an increased risk of patient-reported pain and disability on the FAST pitcher module.

Conclusion: College baseball pitchers with less neck mobility during the preseason had an increased risk of time loss and shoulder and elbow disability during the season. The predictive value of these measures as part of a risk screening profile should be further explored.

Keywords: cervical spine; injury prevention; injury risk; overhead athlete

The incidence of upper extremity injuries in baseball players has been on the rise at all levels of play for the past 3 decades.^{6,11,14,21,41,43,58} The most concerning factor in this trend is the persistent increase of serious injuries in younger pitchers, with a recent review predicting that in the next decade, the average annual incidence of ulnar collateral ligament injuries due to throwing in male

athletes aged 15 to 19 years will double from 6.3 per 100,000 to 14.6 per 100,000.³²

Current practices aimed at preventing throwing-related injuries in baseball include pitch count restrictions and recommendations for days of rest, but comprehensive evidence-based prevention programs are still in development. The identification of important risk factors is fundamental to developing effective injury prevention programs.^{3,10,19,52} Pitch velocity,^{26,37,40} pitch volume,^{18,21,31} arm fatigue,^{30,37,56} and poor pitching mechanics^{8,31} may all increase the risk of throwing-related shoulder or elbow injuries in baseball pitchers. Studies of intrinsic physical

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risk factors have primarily targeted shoulder anatomy and impairments, including humeral torsion,⁵³ reduced glenohumeral range of motion,^{4,23,45-47,54,55} rotator cuff weakness,^{47,50,51} and altered scapular kinematics.²⁴ However, because pitchers depend on effective load transfer across the kinetic chain to optimize efficiency and performance, other body regions should be considered with respect to the injury risk.^{9,17}

Given the anatomic, neurophysiological, and functional relationships between the spine and upper extremity, the cervical and thoracic regions are reasonable targets for the investigation of risk factors related to throwing-related injuries.^{9,16,29,42} In 1996, Young et al⁵⁷ proposed that the neck may play a role in shoulder injuries for overhead throwers because of anatomic relationships and their role in target acquisition and force generation. This hypothesis is consistent with research demonstrating a relationship between cervicothoracic dysfunction and painful upper extremity conditions.^{1,5,35,38,39,49} For example, a recent cohort study⁴² reported that youth baseball players with a kyphosis measure of $>30^\circ$ had a 2.5-times greater odds of developing medial elbow injuries. This lends credence to the notion that spinal mobility impairments contribute to shoulder and elbow problems in throwing athletes.

Most authors of prospective research on the baseball injury risk have focused on time-loss injuries, which are typically defined as “injuries that restrict the athlete’s participation for at least 24 hours beyond the report of injury.”²⁷ However, numerous studies^{22,30,33,37,56} have demonstrated that a high percentage of baseball pitchers continue to pitch with arm pain. Consequently, measuring time loss likely presents an incomplete picture of disability attributed to shoulder and elbow injuries, and the addition of patient-reported outcomes may be more comprehensive.

To date, physical measures of neck mobility and their potential influence on throwing-related injuries have not been examined. Additionally, the limited definition of an injury through time loss does not comprehensively measure the burden of injuries experienced by baseball pitchers. The primary purpose of this study was to prospectively investigate the relationship between measures of neck mobility and posture and the development of shoulder and elbow injuries, pain, and disability in college baseball pitchers across a single season, as quantified by both time loss and patient-reported outcomes. Based on pilot data, we hypothesized that pitchers with reduced upper cervical rotation would be at a greater risk of shoulder and elbow injuries.

Additionally, we investigated the timing of injuries from the beginning of the season to the final competition.

METHODS

We conducted a prospective study across a single college baseball season. The University of Connecticut Institutional Review Board approved the protocol before participant recruitment, and all participants completed informed consent forms before data collection.

Participants

Pitchers were recruited from 2 National Collegiate Athletic Association (NCAA) Division I and 1 NCAA Division III college baseball teams in January 2018 and were screened for eligibility at the time of consent. Eligible pitchers were aged ≥ 18 years and medically cleared to participate in baseball activities. Pitchers were excluded from the study if they were younger than 18 years or had a current shoulder or elbow injury that precluded participation in baseball activities. Based on an α level of 0.05, power of 0.80, and correlation coefficient (r) of 0.448 from preliminary data, the required sample size was 37 (MedCalc for Windows version 17.0; MedCalc Software). This was consistent with recommendations by Flahault et al²⁰ in which, based on an expected sensitivity of 0.89 and minimal acceptable lower confidence limit of 0.70, a sample size of 41 for diagnostic accuracy studies was indicated.

Examiners

A licensed physical therapist/athletic trainer and 4 trained Doctor of Physical Therapy (DPT) students collected all physical measurements and baseline patient-reported outcomes. Raters attended 2 training sessions before initial data collection to improve the consistency and fidelity of the measurement techniques. The same rater performed the same measure at each testing session, and all physical measures demonstrated acceptable intrarater reliability according to intraclass correlation coefficients (ICCs; $ICC_{2,1} = 0.74-0.99$) and standard errors of measurement (SEMs; $2.0^\circ-6.8^\circ$).

Data Collection

During the early preseason, pitchers completed an informational questionnaire and validated baseline patient-reported outcome measures. Height, weight, and physical

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Ethical approval for this study was obtained from the University of Connecticut Institutional Review Board (protocol No. H17-307).

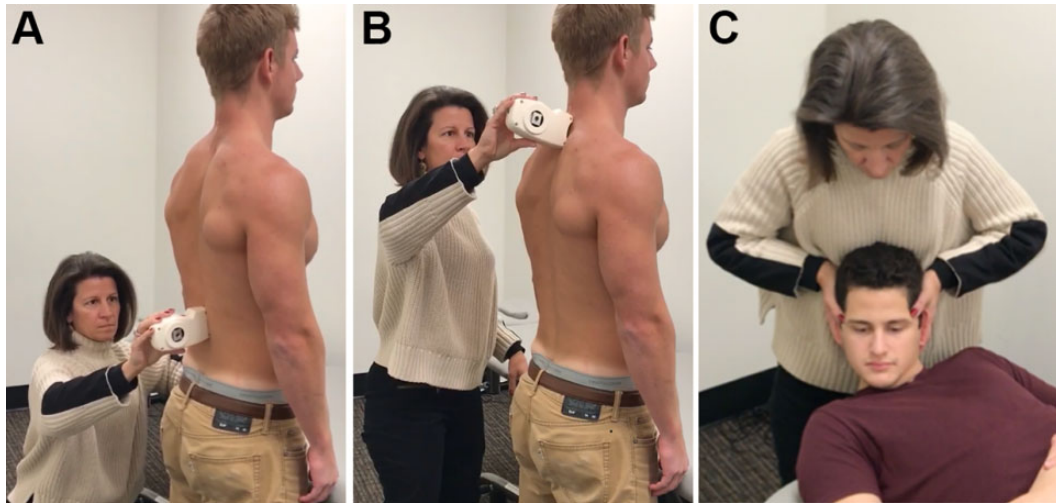


Figure 1. (A) Inclinometric kyphosis measure of the thoracolumbar angle. While maintaining light contact with the skin, the inclinometer was moved superiorly along the spine until the curve first reversed, and the angle was recorded in degrees. (B) Inclinometric kyphosis measure of the cervicothoracic angle. While maintaining light contact with the skin, the inclinometer was moved superiorly along the spine until the curve first reversed, and the angle was recorded in degrees. (C) Cervical Flexion-Rotation Test. The neck was fully flexed with the participant's occiput resting against the examiner's abdomen, and a modified CROM goniometer was positioned at the middle of the top of the head to measure cervical rotation in a fully flexed position. The examiner passively rotated the head until she felt firm resistance.

measurements were also obtained at this time, as described later, and took place on days when players had not thrown within the past 3 days to control for acute changes in mobility secondary to throwing. Throughout the season, we assessed pain and disability biweekly and tracked time loss and game pitch counts weekly.

Informational Questionnaire. The informational questionnaire included age, hand dominance, shoulder and elbow injury history, months pitched in the previous season, and playing status in the previous season (*playing with pain, playing without pain, unable to play because of pain, or unable to play because of other reason*).

Pitch Count. A staff member selected from each team, either the head athletic trainer or pitching coach, tallied game pitch counts weekly and submitted them to the primary investigator (L.L.D.).

Physical Measures. The inclinometric kyphosis measure is a reliable and valid clinical measure of posture with excellent intrarater reliability (ICC = 0.94 [95% CI, 0.89-0.96]; minimal detectable change [MDC] = 8°), excellent interrater reliability (ICC_{2,1} = 0.98 [95% CI, 0.94-0.99]; $P < .001$; SEM = 1.28°; MDC = 3.55°), and construct validity with other postures ($r = 0.72$ [95% CI, 0.36-1.08]; $P = .001$).¹³

Each pitcher was measured in both the usual posture (relaxed) and best posture (cued) using the MicroFET3 digital inclinometer (Hoggan Scientific) as outlined by Devaney et al.¹³ A total of 2 trials were performed, and the mean measurement was recorded (Figure 1, A and B).

Cervical active range of motion was measured in 6 directions (flexion, extension, right/left lateral flexion, and right/left rotation) with the CROM goniometer device (Performance Attainment Associates) as described by Audette

et al.² Before measurements, the examiner demonstrated the 6 cervical motions to be performed, and participants performed a familiarization trial of each motion. Each participant then performed 2 trials of each motion through a comfortable but complete range, and the mean of the 2 scores was recorded. The CROM device has excellent reproducibility (ICC = 0.93-0.98; SEM = 1.6°-2.8°; MDC = 3.6°-6.5°) across the 6 movements.²

The Cervical Flexion-Rotation Test (CFRT) is a valid and reliable test used to identify impaired upper cervical mobility (Figure 1C).⁵ This test uses ligamentous tension to localize motion to the atlantoaxial joint; it was performed as described by Blanpied et al.⁵ using a modified CROM device to obtain each measurement.³⁶ A second examiner recorded the goniometric measurements. There were 2 trials performed in each direction, with the mean of the 2 trials recorded. Mean range of motion is reported to be 39° to 45° in healthy adults.⁵

Glenohumeral passive range of motion was measured with the MicroFET3 digital inclinometer. Internal rotation, external rotation, and horizontal adduction were measured bilaterally in the supine position with the scapula stabilized as described by Shanley et al.⁴⁵ Shoulder flexion was assessed in the supine position with the hips and knees flexed and the lateral border of the scapula firmly stabilized by the hand of the examiner, as illustrated by Wilk et al.⁵⁴ Two examiners performed each measurement, with one examiner identifying the end range and the other recording the measurement. Examiners were blinded to hand dominance, and the primary examiner was blinded to the values. There were 2 trials performed for each motion, and their mean was recorded. The reliability of inclinometer measurements at the shoulder is excellent, with an ICC for

intrarater reliability of 0.97 and 0.98, respectively, and an SEM of 2°. ¹²

Time Loss. Time loss was recorded as any athlete-exposure missed because of shoulder or elbow complaints. A time-loss injury was defined as any shoulder or elbow condition that resulted in an inability to participate in baseball activities for >7 days. The injury rate was calculated as the number of injuries per 1000 game pitches, as this may be a better indicator of the injury risk in pitchers than the number of injuries per athlete-exposure. A staff member selected from each team, either the head athletic trainer or pitching coach, collected time-loss data weekly and submitted them to the primary investigator.

Patient-Reported Outcome Measures. The Functional Arm Scale for Throwers (FAST) is a region- and population-specific patient-reported outcome tool developed to measure health-related quality of life in throwing athletes. ⁴⁴ The FAST consists of 22 items and a 9-item pitcher module specific to baseball that may be interpreted independently. The FAST and the FAST pitcher module are converted to a 100-point scale, with a higher score indicating greater pain and disability. Both the FAST and the FAST pitcher module are reliable, valid, responsive, and able to discriminate between injured and uninjured players. ²⁵

Pitchers completed all patient-reported outcome measures at baseline testing, and they completed the FAST pitcher module every 2 weeks to measure pain and disability. In-season pain and disability outcome measurements were collected through the Qualtrics online platform and directly routed to the primary investigator.

Statistical Analysis

Means and standard deviations were calculated for each variable. Total glenohumeral rotation range of motion was calculated for each arm by adding the mean internal rotation and mean external rotation values. Differences in values were calculated between the dominant (throwing arm) and nondominant sides for cervical active range of motion lateral flexion and rotation, the CFRT, and glenohumeral passive range of motion.

For time-loss analysis, participants were considered “injured” if they missed >7 days. For patient-reported outcome analysis, FAST pitcher module scores were averaged across the season. Participants were considered “injured” if their FAST pitcher module mean score was >10, as a score of >10 has been shown to distinguish between injured and uninjured high school and college pitchers. ²⁵ Data were not normally distributed, so group differences (injured vs uninjured) were analyzed using the Mann-Whitney *U* test. Receiver operating characteristic (ROC) curves were generated for variables with significance at $P < .10$ to plot sensitivity, specificity, and cutoff values to estimate the diagnostic utility of the measures as screening tools. Participants were dichotomized into “positive” and “negative” groups for the tests based on cutoff values that optimized sensitivity, as recommended by Bahr, ³ and positive predictive values, negative predictive values (NPVs), and risk ratios (RRs) were computed. Moreover, 95% confidence

intervals (CIs) around the risk estimates were calculated to obtain a candid and realistic interpretation of the clinical meaning of these values. Additionally, we performed an analysis of time to first injury to appreciate the timing of injuries during the season.

Statistical analyses were performed with SPSS (version 24; IBM) and MedCalc (version 17.9) with an a priori significance level of $P < .05$ and minimal area under the curve (AUC) of 0.70 for ROC analysis.

RESULTS

A total of 49 college baseball pitchers (mean age, 19.9 ± 1.5 years; mean height, 187.0 ± 6.0 cm; mean weight, 89.1 ± 12.1 kg) completed the study. There were 38 pitchers (77.6%) who were right-hand dominant, and 34 (69.4%) played at the Division I level. Moreover, 21 pitchers (42.9%) reported a history of shoulder or elbow injuries, and 17 (34.7%) reported that they had pitched with arm pain in the previous season.

Time-Loss Injury

All 49 participants enrolled were included in the time-loss analysis. While 2 pitchers left their team for reasons other than an injury late in the season, they had missed no time because of shoulder or elbow pain, reported no shoulder or elbow complaints, and were thus included in the final analysis. Of the 49 participants, 20.4% (10/49) suffered a shoulder or elbow injury resulting in >7 days lost. The mean number of days lost was 7.2 ± 17.8 days (range, 0-56 days) with a total of 380 days lost. The injury incidence was 0.47 per 1000 game pitches. A total of 6 players had elbow injuries, 3 had shoulder injuries, and 1 had both shoulder and elbow complaints.

Means and standard deviations for all physical measures are reported in Table 1. Figure 2 illustrates the overall differences in preseason neck and shoulder mobility between the injured and uninjured groups. While preseason shoulder mobility was the same for both groups, injured pitchers had significantly less motion according to the CFRT on the dominant side versus uninjured pitchers ($P = .03$), with a mean difference of 4.2° (Table 1).

The ROC curve in Figure 3 shows the relationship between sensitivity and 1 – specificity for the CFRT and represents the ability of the test to discriminate between injured and uninjured pitchers. Statistically, a cutoff score of <39.25° optimized sensitivity (0.90 [95% CI, 0.55-1.00]) and specificity (0.62 [95% CI, 0.45-0.77]) and best distinguished pitchers who sustained a time-loss injury from those who did not (AUC = 0.73 [95% CI, 0.55-0.90]; $P = .03$). Of the 10 pitchers who suffered a time-loss injury, only 1 had a preseason CFRT finding of >39.25°. A more pragmatic measurement cutoff for the clinician is a whole number of 39°. Therefore, diagnostic values reported in Table 2 were calculated based on a cutoff score of ≤39°. Ultimately, pitchers with a ≤39° finding on the CFRT had an over 9 times greater risk of time-loss injuries versus those with more mobility (RR, 9.38 [95% CI, 1.28-68.49]).

TABLE 1
Preseason Physical Measurements in Injured and Uninjured Players^a

	Uninjured (n = 39)	Injured (n = 10)	P Value
Height, cm	183.9 ± 6.1	184.7 ± 5.6	.76
Weight, kg	88.5 ± 12.3	91.5 ± 11.3	.41
Inclinometric kyphosis measure, deg			
Relaxed	132.9 ± 6.9	134.3 ± 9.8	.69
Cued	138.0 ± 7.0	139.8 ± 10.5	.63
CFRT, deg			
Dominant	38.3 ± 6.6	34.1 ± 7.5	.03
Nondominant	38.7 ± 5.2	36.6 ± 7.8	.25
Difference	-0.4 ± 5.5	7.6 ± 3.5	.32
Cervical range of motion, deg			
Flexion	64.6 ± 9.9	58.0 ± 13.2	.08
Extension	70.8 ± 7.8	71.9 ± 9.8	.60
Lateral flexion, deg			
Dominant	41.4 ± 5.6	43.1 ± 7.6	.58
Nondominant	43.9 ± 4.8	43.7 ± 9.7	.60
Difference	-2.5 ± 8.0	-0.6 ± 3.7	.48
Rotation, deg			
Dominant	68.5 ± 6.3	66.9 ± 11.5	.49
Nondominant	68.5 ± 5.9	67.3 ± 11.2	.38
Difference	0.0 ± 8.3	-0.4 ± 5.4	.53
Glenohumeral passive range of motion, deg			
Internal rotation			
Dominant	46.3 ± 7.7	45.3 ± 8.5	.50
Nondominant	54.4 ± 6.8	53.8 ± 11.1	.86
Difference	-8.1 ± -8.5	8.6 ± 9.5	.89
External rotation			
Dominant	95.6 ± 6.5	95.0 ± 7.8	.71
Nondominant	86.0 ± 9.5	86.3 ± 9.1	.84
Difference	9.5 ± 8.7	8.3 ± 9.0	.62
Flexion			
Dominant	133.6 ± 12.1	133.9 ± 11.0	.76
Nondominant	131.9 ± 11.6	129.9 ± 13.1	.63
Difference	1.7 ± 4.0	13.4 ± 12.1	.86
Horizontal adduction			
Dominant	17.9 ± 4.2	17.6 ± 6.5	.53
Nondominant	19.3 ± 5.2	19.8 ± 9.3	.78
Difference	-1.5 ± -2.2	8.3 ± 5.0	.47

^aData are reported as mean ± SD. Bolded value indicates statistical significance (*P* < .05). CFRT, Cervical Flexion-Rotation Test.

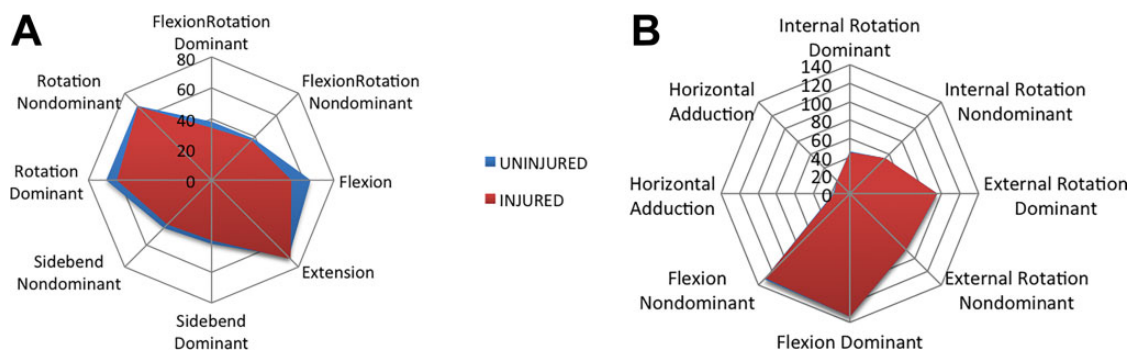


Figure 2. Preseason physical measurements for injured and uninjured pitchers. (A) Neck mobility. (B) Shoulder mobility.

Time to Injury

The curve in Figure 4 illustrates the timing of each time-loss injury and compares pitchers who had >39.25° and

≤39.25° findings on the CFRT. All but 1 pitcher with a >39.25° finding completed the entire season without a time-loss injury, and the mean time to initial injury onset was significantly different between the 2 groups

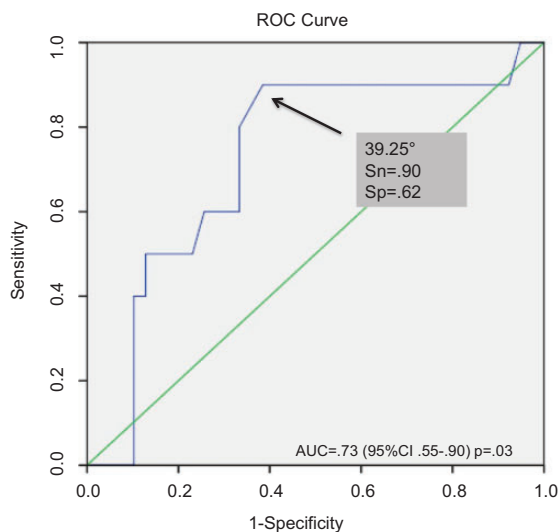


Figure 3. Receiver operating characteristic curve for the Cervical Flexion-Rotation Test on the dominant side and time loss.

($\chi^2 = 7.667$; $P = .01$). Over a 112-day season, pitchers with a $>39.25^\circ$ finding on the CFRT played a mean 109.4 days (95% CI, 105-114) without an injury versus 83.6 days (95% CI, 68-99) for pitchers with a $\leq 39.25^\circ$ finding.

Patient-Reported Pain and Disability

Patient-reported outcome analysis was based on 37 pitchers, with a response rate of 75.5%. A total of 12 pitchers were excluded from the analysis because of a lack of compliance with in-season reporting. Overall, 29.7% (11/37) of pitchers were categorized as injured (mean FAST pitcher module score >10), with a mean score of 24.0 ± 10.6 (range, 11.1-42.1). Uninjured pitchers had a mean score of 2.7 ± 3.2 (range, 0.0-9.7). Injured pitchers had less motion according to both the CFRT on the dominant side ($P = .03$) and cervical flexion range of motion ($P = .01$) (Figure 5). Additionally, injured pitchers were heavier ($P = .01$) and had less of a side-to-side difference in glenohumeral external rotation ($P = .02$). No other physical measurements differed between the groups.

The ROC curves generated optimal cutoff values of 38.25° for the CFRT on the dominant side (AUC = 0.73 [95% CI, 0.54-0.92]; $P = .03$), 64° for cervical flexion range of motion (AUC = 0.76 [95% CI, 0.60-0.92]; $P = .01$), 86.86 kg for weight (AUC = 0.78 [95% CI, 0.60-0.96]; $P = .01$), and

11.75° for the side-to-side difference in glenohumeral external rotation. Diagnostic values as reported in Table 3 were calculated based on pragmatic cutoff scores as labeled. Pitchers with a $\leq 38^\circ$ finding on the CFRT had a nearly 4 times greater risk of reporting shoulder or elbow pain and disability (mean FAST pitcher module score >10). Pitchers with $\leq 64^\circ$ cervical flexion range of motion had over a 10 times greater risk, and pitchers heavier than 86.9 kg had over a 10 times greater risk. A side-to-side difference in external rotation of $\leq 12^\circ$ also increased the risk, but the 95% CI crossed 1, indicating that this could be caused by chance.

DISCUSSION

Primary Outcome

The most important finding of this study was that the pre-season CFRT finding on the dominant side was associated with an increased risk of a shoulder or elbow injury, resulting in both time loss and self-reported pain and disability. Additionally, limited cervical flexion range of motion resulted in a greater risk of self-reported pain and disability.

The high sensitivity and NPVs for the cervical mobility measures suggest that the CFRT and cervical flexion range of motion may identify pitchers at a higher risk of sustaining throwing-related shoulder and elbow injuries. Pitchers identified as high risk could then be targeted with interventions to reduce the incidence of injuries.

The study results support the premise that the neck plays a role in the cause of throwing-related shoulder and elbow injuries. While the underpinnings of this relationship are unclear, limited neck mobility may influence the pitcher's ability to maintain head stability during the later phases of the pitching motion. For example, during late cocking, acceleration, and follow-through, the trunk rapidly flexes, rotates, and laterally flexes on a fixed head (creating repeated relative neck extension, right rotation, and right lateral flexion for a right-handed pitcher) (Figure 6).

A reduction in upper cervical rotation mobility requires compensatory midcervical motion (rotation, lateral flexion, and extension) to maintain the head in space. These combined motions may decrease the space for the nerve roots in the intervertebral foramina with consequent myotomal changes that impair scapular and glenohumeral neuromuscular performance.²⁹ Additionally, if neck mobility restrictions interfere with the execution of sequential, coordinated movements necessary for pitching success, there may be a

TABLE 2
Diagnostic Values of Time-Loss Injuries (N = 49)^a

	Positive Likelihood Ratio (95% CI)	Negative Likelihood Ratio (95% CI)	Positive Predictive Value (95% CI), %	Negative Predictive Value (95% CI), %	RR (95% CI)
CFRT on dominant side $\leq 39^\circ$	2.34 (1.50-3.66)	0.17 (0.02-1.06)	37.5 (27.7-48.4)	96.0 (78.6-99.4)	9.38 ^b (1.28-68.49)

^aCFRT, Cervical Flexion-Rotation Test; RR, risk ratio.

^b $P < .05$.

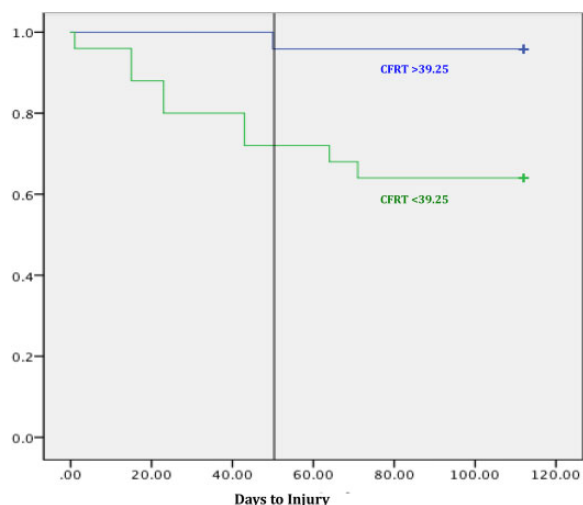


Figure 4. Time-to-injury analysis: Cervical Flexion-Rotation Test (CFRT) on the dominant side.

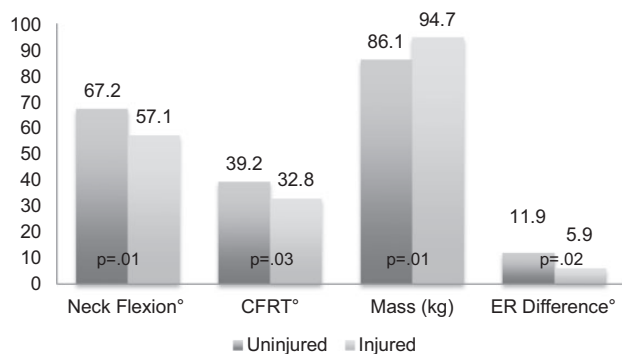


Figure 5. Physical measurements in injured versus uninjured pitchers: self-reported disability. CFRT, Cervical Flexion-Rotation Test; ER, external rotation.

logical link between cervical dysfunction and throwing-related shoulder and elbow injuries.¹⁵ This is consistent with the generally accepted concept that proximal dysfunction alters distal function. These explanations are speculative, and the nature of the relationship between neck mobility and arm injuries needs further investigation with respect to establishing causation.

An interesting incidental finding was the fact that heavier pitchers had an increased risk of patient-reported pain and disability on the FAST pitcher module. Chalmers et al⁷ reported a similar relationship in that Major League Baseball players who had undergone ulnar collateral ligament reconstruction were heavier than their noninjured counterparts. One possible explanation is that heavier players throw harder, resulting in increased forces through the shoulder and elbow, but this would likely result in structural or time-loss injuries. Interestingly, there is emerging evidence that adiposity is linked to musculoskeletal pain complaints, but without an assessment of body

composition, we cannot infer that this played a role in pain and disability.

A secondary purpose of this study was to examine the timing of injury during the season with respect to preseason neck mobility measures. The survival analysis illustrated that most injuries occurred during the first half of the season, with all injured pitchers missing time by the 10th week of the season. In general, pitchers with more upper cervical rotation mobility on the dominant side survived the season. These results suggest that preseason screening may play an important role in identifying pitchers at risk and may allow for preventive interventions. Exercise and mobilization effectively increase impaired neck mobility; thus, these neck mobility measures have potential as modifiable risk factors.⁵

Strengths

This research fills an important gap in the risk profile for baseball pitchers as the first study to investigate the relationship between neck mobility and shoulder and elbow injuries. The magnitude of the increased risk indicates that neck mobility impairments have a place alongside other previously identified risk factors as part of a screening and intervention strategy. Several authors have reported that limitations in glenohumeral mobility increase the risk of shoulder and elbow injuries by 4 to 6 times in junior and high school baseball players⁴⁵⁻⁴⁷ and 2 to 3 times at the professional level.⁵⁴ In our study, preseason glenohumeral range of motion was not significantly different between the injured and uninjured groups. This could be because of differences in the study population, sample size, or implementation of arm care programs. However, as Figure 2 indicates, injured pitchers had a profile of less neck mobility than uninjured pitchers with the exception of neck extension, with significant differences in upper cervical rotation (time-loss injury) and neck flexion (self-reported injury). The addition of neck mobility measures to previously identified risk factors is a step forward on the path to understanding the multifactorial risk profile.

Another strength of this study was the multifaceted assessment of injuries. We chose to define a time-loss injury as one that resulted in >7 days for consistency with recent research^{47,48} and because, in practical terms, missing more than a week of play during a relatively short season represents a significant impact on the pitcher and the team.²⁸ Interestingly, a visual inspection of our data suggested that those who missed >7 days were indeed a distinct group: pitchers who missed >7 days ended up missing at least 21 days, which is similar to prior research.³⁴ Therefore, our definition seems to be a pragmatic measure of significant time-loss injuries.

In addition to time loss, we gathered patient-reported outcome data to provide a more comprehensive picture of the burden of disability. Up to this point, most prospective studies regarding the risk of throwing-related injuries have defined injuries only in terms of time loss. Kerr et al²⁷ reported that baseball had the highest percentage of non-time-loss injuries of all college sports from 2009 to 2014, suggesting that players often participate while suffering

TABLE 3
Diagnostic Values of Patient-Reported Pain and Disability (n = 37)^a

	Sensitivity	Specificity	Positive Likelihood Ratio (95% CI)	Negative Likelihood Ratio (95% CI)	Positive Predictive Value (95% CI), %	Negative Predictive Value (95% CI), %	RR (95% CI)
CFRT on dominant side $\leq 38^\circ$	0.73 (0.39-0.94)	0.73 (0.52-0.88)	2.70 (1.30-5.60)	0.37 (0.14-1.01)	53.3 (35.5-70.3)	86.4 (70.1-94.5)	3.91 ^b (1.23-12.39)
Cervical flexion range of motion $\leq 64^\circ$	0.91 (0.59-1.00)	0.69 (0.48-0.86)	2.95 (1.61-5.42)	0.13 (0.02-0.87)	55.6 (40.5-69.6)	94.7 (73.2-99.2)	10.56 ^b (1.50-74.34)
Weight >86.9 kg	0.91 (0.59-1.00)	0.69 (0.48-0.86)	2.94 (1.60-5.40)	0.13 (0.02-0.81)	57.9 (3.1- 71.4)	94.4 (71.9-99.1)	10.42 ^b (1.14-213.70)
Side-to-side difference in external rotation $\leq 12^\circ$	0.81 (0.48-0.98)	0.54 (0.33-0.73)	1.77 (1.08-2.92)	0.34 (0.09-1.24)	42.9 (31.3-55.3)	87.5 (65.5-96.3)	3.42 (0.86-13.73)

^aCFRT, Cervical Flexion-Rotation Test; RR, risk ratio.

^b $P < .05$.



Figure 6. Trunk flexion, contralateral side bending, and contralateral rotation at (A) ball release and (B) follow-through.

some level of pain and disability. The fact that limited neck mobility was associated with both time loss and patient-reported outcomes in the current study lends even more credibility to the clinical utility of including neck mobility measures in this population.

Limitations

The results of this study should be interpreted conservatively. In an ecological study, factors such as weather and game scheduling are not controlled and may exert influence

on the injury risk. Additionally, we only included game pitch counts in our calculation of the injury incidence because of inconsistencies across teams in recording warm-up and bullpen workouts. This may have overestimated or underestimated the workload for a given pitcher. Also, we did not have peak and average pitch velocity data, which would have further strengthened the analysis. Furthermore, we delimited our assessment to more proximal joints (cervical and shoulder). Specifically, elbow range of motion was not assessed, and this can be a risk factor for elbow injuries.

Out of convenience, we studied 2 different competition levels. Interestingly, the only injured pitcher without neck stiffness was a Division III pitcher. Given the variety in schedules and overall physical demands, it is possible that the different competition levels have different risk profiles. The study was adequately powered for the primary question, but a larger sample would have produced a more precise estimate of the relative risk attributable to limited neck mobility and would have allowed us to tease out distinctions between shoulder and elbow injuries.

Prior research suggests that each competition level may have a unique risk profile; our results may be specific to college pitchers and perhaps only those playing in northern climates. Therefore, it is premature to extrapolate to different age groups and geographic regions where baseball is played year round. Finally, although we found that neck mobility predicted the injury risk in this cohort, we cannot assume that improving neck mobility will lead to reduced injury rates, and this hypothesis should be tested with a well-designed intervention study.

Future Directions

To further understand neck mobility in the context of the baseball injury risk, broader validation of the results is necessary to generalize across ages and competition levels. Injury outcomes should ideally include time loss, non-time loss, and patient-reported outcomes to illustrate the full burden of shoulder and elbow injuries on baseball pitchers. Additionally, neck mobility should be assessed in the context of a mixed-model multifactorial analysis to identify predictors and interactions that are sufficiently strong to warrant an injury prevention intervention.

CONCLUSION

Preseason neck mobility measurements were associated with shoulder and elbow time-loss injuries and self-reported pain and disability in college baseball pitchers over the course of a season. The CFRT and cervical flexion range of motion demonstrated high sensitivity and NPV and therefore may be useful screening tools in developing a risk profile for individual pitchers.

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