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Risk Factors for Shoulder and Elbow Injuries in High School Baseball Pitchers

The Role of Preseason Strength and Range of Motion

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Background: Shoulder strength and motion deficits in high school baseball pitchers have been implicated in injury risk.

Purpose/Hypothesis: To prospectively determine if preseason strength and range of motion (ROM) are predictive of injury in high school baseball pitchers. It was hypothesized that ROM asymmetries and weakness would be predictive of injury.

Study Design: Case-control study; Level of evidence, 3.

Methods: Preseason strength and ROM measurements were made on 101 pitchers from 4 different high schools over 4 seasons (total 166 pitcher-seasons: 25 freshman, 46 junior varsity, and 95 varsity player-seasons). Glenohumeral internal rotation (IR), glenohumeral external rotation, and posterior shoulder ROM were measured bilaterally. Strength in IR, external rotation, supraspinatus (empty-can test), and scapular retraction was measured bilaterally (handheld dynamometer). Injury incidence (injuries per 1000 pitches) was computed for players categorized as above normal ($\geq$1 SD above the mean), normal (within 1 standard deviation of the mean), and below normal ($\leq$1 SD below the mean) for each potential risk factor. Injury was defined as a missed game or practice because of shoulder or elbow problem.

Results: There were 28 upper extremity injuries (19 shoulder, 9 elbow; incidence, 0.58 injuries/1000 pitches). There was a trend for supraspinatus weakness to be associated with increased injury risk (relative risk [RR], 3.60; 95% CI, 0.75-17.32; P = .09). When analyzing major injuries only ($>$3 missed games), preseason supraspinatus weakness was significantly associated with increased injury risk (RR, 4.58; 95% CI, 1.40-15.01; P = .02). Paradoxically, pitchers with no IR loss were at increased risk compared with pitchers with $\geq$20° loss (RR, 4.85; 95% CI, 1.01-23.29; P = .04). Other ROM and strength measures were unrelated to injury risk.

Conclusion: Although excessive loss of IR ROM is thought to be a risk factor for injury, the opposite was the case in this study. The absence of IR ROM loss in high school pitchers may indicate inadequate prior exposure to pitching, resulting in increased injury risk. Preseason supraspinatus weakness was associated with increased risk for a major injury, and preventative supraspinatus strengthening may be beneficial.

Keywords: shoulder; baseball; elbow; epidemiology

Adaptations in range of motion (ROM) and strength have been identified in the throwing arms of baseball pitchers at all playing levels and ages.[1,2,5-8,11,13,16] Specifically, the loss of glenohumeral internal rotation (IR) ROM in the throwing arm has been recognized.[6,8,13,16] Additionally, Reinold et al[11] demonstrated acute loss of IR ROM after a pitching outing. Shanley et al[12] reported IR ROM loss to be a significant risk factor for injury in high school baseball and softball players. However, there was no differentiation between baseball and softball players or between pitchers and nonpitchers. Therefore, it was unclear whether the risk was due to IR ROM loss or simply that baseball pitchers had greater IR ROM loss and had a greater prevalence of injury because of their greater volume and intensity of throwing. IR loss has been shown to be greater in pitchers than position players,[1] and pitchers have been shown to be more susceptible to injury.[3,4] Wilk et al[16] did not find IR ROM loss to be related to injury risk in professional

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baseball pitchers. However, loss of total ROM was associated with increased risk in these professional pitchers.

In addition to glenohumeral ROM deficits, baseball pitchers have also been shown to have posterior shoulder (PS) tightness on the dominant versus nondominant side and compared with controls.[15] PS tightness has been associated with shoulder injury in baseball pitchers[10]; pitchers with impingement syndrome were shown to have greater PS tightness and IR ROM loss than uninjured players.[10]

With respect to shoulder strength, preseason weakness in glenohumeral external rotation (ER) and supraspinatus strength was associated with throwing-related upper extremity injuries resulting in surgical intervention in professional baseball pitchers.[2] Additionally, lower ER versus IR strength was also associated with increased risk for injury. In that study strength was measured only on the dominant arm, so there was no analysis of whether side-to-side differences in strength were related to injury risk. There also was no measure of exposure, so it was unclear how the strength factors affected injury incidence.

In high school pitchers, an association has been found between shoulder pain during the season and postseason strength imbalances between the propulsive muscles and the stabilizers and decelerators.[13] Specifically, pitchers who reported pitching with shoulder pain had greater strength in IR and lower strength in the supraspinatus and middle trapezius compared with pitchers without pain. Because the strength measures were made in the postseason, it was unclear if the observed strength differences were a result or a cause of the shoulder pain. Furthermore, it was unclear if the reported shoulder pain was a precursor of injury. Nine of the pitchers had missed games because of their shoulder pain.

It is apparent that the existing literature on the role of strength and ROM as risk factors for shoulder and elbow injuries in baseball pitchers is inconclusive. Confounding factors such as inadequate measures of exposure,[2,16] the inclusion of pitchers and nonpitchers in softball and baseball,[12] and retrospective study designs[10,13] make it difficult to make concise conclusions. Therefore, the purpose of this study was to prospectively assess the role of preseason shoulder strength and ROM on the subsequent incidence of shoulder and elbow injuries in a sample of high school baseball pitchers. To get an appropriate measure of exposure, pitch counts were recorded for all game situations, and injury incidence was calculated per 1000 pitches thrown in game situations. On the basis of the existing literature, we hypothesized that total ROM loss,[16] IR ROM loss,[12] PS tightness,[10] and supraspinatus weakness[2,13] might be associated with increased risk for injury.

MATERIALS AND METHODS

Preseason strength and ROM measurements were made on 101 pitchers from 4 different high schools. Five pitchers were tested before 4 consecutive seasons, 12 before 3 seasons, 26 before 2 seasons, and 58 before 1 season (total 166 pitcher-seasons: 25 freshman, 46 junior varsity, and 95 varsity player-seasons). The study was approved by the institutional review board, and written assent and consent were provided by participants and their guardians.

Figure 1. Measurement technique for posterior shoulder tightness, with the tester positioning the arm and stabilizing the scapula and the recorder placing the digital level on the humerus.

ROM Measurements

The IR, ER, and PS ROM was measured bilaterally using a digital level. Intra- and intertester reliability has been established for these measurements.[9] Passive IR ROM was measured in the supine position with the shoulder in 90° of abduction and with the elbow in 90° of flexion. The digital level was aligned with the forearm while the shoulder was passively rotated. The ER ROM was measured similarly. PS ROM (Figure 1) was measured in the side-lying position, with the shoulder and elbow flexed to 90°. The tester manually stabilized the axillary border of the scapula when the arm was placed in 90° of shoulder abduction and 90° of elbow flexion (starting position). This scapular position was maintained as the arm was lowered.[15] The digital level was aligned with the humerus, and the angle relative to the horizontal was recorded (cross-chest abduction angle).

Strength Measurements

Strength in IR, ER, supraspinatus (empty-can test), and scapular retraction was measured bilaterally with a handheld dynamometer (Lafayette Manual Muscle Tester, Lafayette, Indiana, USA) using the break test. This instrument and measurement technique have been shown to be valid and reliable for detecting weakness in the shoulder.[8,14] The IR strength was measured in the supine position with the shoulder in 90° of abduction and the elbow in 90° of flexion. The arm was placed in neutral rotation, and

the subject maximally resisted against the dynamometer placed on the volar aspect of the wrist. We tested ER strength in a similar manner, with the dynamometer placed on the dorsal aspect of the wrist. Supraspinatus strength was measured in the sitting position with the shoulder flexed 90° in the scapular plane, the elbow in full extension, and the shoulder fully internally rotated (thumb down; ie, empty-can test). The dynamometer was placed on the ulnar aspect of the wrist, and the subject maximally resisted a downward force. Scapular retraction strength was measured in the prone position with the shoulder abducted 90° and the elbow in 90° of flexion. The dynamometer was placed at the elbow, and the subject maximally resisted a downward-directed force. The average of 3 repetitions was recorded for each arm in each strength test.

Injury Tracking

An injury was defined as any physical problem that resulted in at least 1 missed game or practice. A missed game was defined as a game in which a pitcher could have started if it were not for the injury (ie, not just games the pitcher was scheduled to pitch in). Any shoulder or elbow injury was recorded for the purposes of identifying risk factors. All injuries were recorded by the certified athletic trainer or physical therapist assigned to the particular team. Diagnoses were confirmed by the study orthopaedic surgeon (S.J.N.). In addition to recording the number of games and practices participated in for each player, pitch counts were made for all pitchers in all games. Injury incidence was calculated as injuries per 1000 pitches.

Statistical Analysis

For all potential risk factors, players were categorized as above normal (≥1 SD above the mean), normal (within 1 SD of the mean), and below normal (≤1 SD below the mean) of the mean value for that risk factor (ie, z score ≥1, –1 to 1, or ≤–1). Seven primary potential risk factors were examined: ROM deficits (dominant – nondominant) in IR, ER, PS, and total ROM and strength deficits (dominant – nondominant/dominant) in IR, ER, supraspinatus, and scapular retraction. Additionally, absolute strength measures on the dominant side were examined as potential risk factors. Injuries per total exposure were compared between z-score groups using χ^2 analyses, and the P value for the linear trend is reported. Where there was a significant linear trend, relative risk (RR) was calculated relative to the group with the low injury incidence for that variable. Injury incidence and, where appropriate, RR are reported with 95% CIs.

We estimated that with normally distributed data, on average, there would be approximately 27 player-seasons in the above- and below-normal groups (68% of the normal distribution within 1 SD of the mean, with 16% above and 16% below 1 SD, respectively; 16% of 166 player-seasons = 27 player-seasons). Assuming this sample size for the above- and below-normal groups, it was estimated that there was 80% power to detect an RR of 4.0 between above- and below-normal groups at $P < .05$. The detectable RR could have been decreased by increasing the overall study sample size or by dividing player-seasons into equal tertiles rather than on the basis of z scores. However, the goal was to identify players significantly above or below normal for a given variable. Furthermore, the ultimate goal was to identify risk factors that were sufficiently strong to warrant an injury prevention intervention. On the basis of previous practical experience, we deemed it impractical to develop interventions to address risk factors where the RR was <4.0 given the limited number of pitchers on a given team.

TABLE 1
Baseline ROM Deficits[a]

	ROM Deficit, deg		
	Mean ± SD	Above Normal[b]	Below Normal
IR ROM	–10 ± 10[c]	≤–20 (n = 25)	≥0 (n = 31)
ER ROM	7 ± 11[c]	≥18 (n = 29)	≤–4 (n = 29)
Total ROM	–1 ± 14	≤–15 (n = 24)	≥13 (n = 20)
PS ROM	–7 ± 14[c]	≤–21 (n = 28)	≥7 (n = 32)

[a]ER, glenohumeral external rotation; IR, glenohumeral internal rotation; PS, posterior shoulder; ROM, range of motion; SD, standard deviation.
[b]For IR ROM, total ROM, and PS ROM, "above normal" refers to excessive loss of ROM on the dominant versus nondominant side.
[c]Significant deficit ($P < .001$).

RESULTS

Injury Incidence

The average ± SD number of games pitched per season per pitcher was 5.6 ± 3.3 (maximum 25 games/season). Pitches per game averaged 48.9 ± 26.8 (maximum 110 pitches/game), and total pitches in a season averaged 290 ± 223 (maximum 973 pitches/season). There were 19 shoulder injuries and 9 elbow injuries, for an injury incidence of 0.58 upper extremity injuries per 1000 pitches. The shoulder injuries included 13 rotator cuff tendinopathies and 6 superior labral anterior-posterior tears. For the elbow, there were 6 ulnar collateral ligament injuries and 3 tendinopathies. Of the 28 injuries, 2 resulted in no missed games (only practices were missed), 10 in 1 missed game, 5 in 2 or 3 missed games, and 11 in >3 missed games.

Baseline ROM and Strength Deficits

The dominant versus nondominant arm had on average 10° ± 10° less IR ROM, 7° ± 11° more ER ROM, 7° ± 14° less PS ROM ($P < .001$ for all), and minimal difference in total ROM (–1° ± 14°, $P = .36$) (Table 1). The IR strength was 7% greater ($P < .001$) in the dominant arm, with no side-to-side differences in other tests (Table 2).

TABLE 2
Baseline Strength in the Dominant Arm and Strength Deficits[a]

	Dominant Arm Strength, N			Dominant vs Nondominant Arm Strength, %		
	Mean ± SD	Above Normal	Below Normal	Mean ± SD	Above Normal	Below Normal
Supraspinatus	95 ± 28	≥123	≤67	1 ± 20	≥21	≤–19
Retraction	128 ± 50	≥178	≤79	1 ± 17	≥18	≤–16
ER	124 ± 36	≥160	≤88	2 ± 22	≥24	≤–20
IR	139 ± 38	≥177	≤101	7 ± 22[b]	≥29	≤–15

[a]ER, external rotation; IR, internal rotation; SD, standard deviation.
[b]Significantly greater strength on the dominant versus nondominant side ($P < .001$).

TABLE 3
Association Between ROM Deficits and Injury Risk[a]

	Effect of ROM Deficits on Injury Risk			
	Above Normal	Normal ROM	Below Normal	*P*
IR ROM loss				
No. of injuries	2/25	19/110	7/31	
Injury incidence[b]	0.23	0.57	1.14	.03
95% CI	0.04-0.79	0.36-0.89	0.55-2.35	
ER ROM gain				
No. of injuries	7/29	17/108	4/29	
Injury incidence[b]	0.73	0.55	0.52	.35
95% CI	0.28-1.89	0.35-0.89	0.20-1.33	
TOTAL ROM loss				
No. of injuries	3/22	21/125	4/19	
Injury incidence[b]	0.45	0.59	0.69	.56
95% CI	0.15-1.33	0.38-0.90	0.27-1.76	
PS ROM loss[c]				
No. of injuries	7/28	18/108	3/24	
Injury incidence[b]	0.89	0.57	0.40	.21
95% CI	0.43-1.83	0.36-0.90	0.13-1.67	

[a]CI, confidence interval; ER, external rotation; IR, internal rotation; ROM, range of motion.
[b]Per 1000 pitches.
[c]PS measurements were not made on 6 players.

Injury Risk Analysis: ROM Deficits

The IR ROM deficit was related to injury risk; injury incidence was 0.23 (95% CI, 0.04-0.79) for pitchers with above-normal loss of IR ROM (≥20°), 0.57 (95% CI, 0.36-0.89) for pitchers with normal IR ROM loss (19°-0° loss), and 1.14 (95% CI, 0.55-2.35) for pitchers with below-normal IR ROM loss (<0° loss) (linear trend $P = .03$) (Table 3). The RR for injury for pitchers with below-normal IR loss was 4.85 (95% CI, 1.01-23.29) relative to pitchers with above normal IR loss. Gain in ER ROM, PS tightness, and loss of total ROM were unrelated to injury risk ($P = .21$-$.56$) (Table 3).

Injury Risk Analysis: Strength Deficits

There was a trend for pitchers with supraspinatus weakness (dominant arm weaker than nondominant) to have increased injury risk compared with pitchers with increased strength on the dominant arm (RR, 3.60; 95% CI, 0.75-17.32; $P = .09$) (Table 4). Deficits in strength for the other 3 strength tests were unrelated to risk (Table 4). Absolute strength was not related to injury risk in the supraspinatus ($P = .20$), ER ($P = .17$), IR ($P = .61$), or retraction ($P = .66$). Similarly, absolute strength relative to body mass was unrelated to injury risk (supraspinatus $P = .17$, ER $P = .33$, IR $P = .70$, retraction $P = .91$).

Because there was a trend for supraspinatus weakness to increase risk for sustaining an upper extremity injury resulting in a missed game or practice, this relationship was further examined for injuries resulting in more than 3 missed games (major injuries; n = 11). The incidence of major injuries was 0.68 (95% CI, 0.29-1.58) for pitchers with preseason supraspinatus weakness compared with 0.15 (95% CI, 0.06-0.35) for pitchers with normal preseason strength and 0.13 (95% CI, 0.02-0.74) for pitchers with above-normal preseason strength (dominant significantly stronger than nondominant) (linear trend $P = .03$). For pitchers with preseason supraspinatus weakness, the RR

TABLE 4
Association Between Strength Deficits and Injury Risk[a]

	Effect of Strength Deficits on Injury Risk			
	Strong[b]	Normal	Weak[c]	*P*
Supraspinatus				
No. of injuries	2/21	19/116	7/29	
Injury incidence[d]	0.28	0.57	0.95	.09
95% CI	0.08-1.01	0.36-0.89	0.46-1.95	
Retraction				
No. of injuries	6/28	18/117	4/21	
Injury incidence[d]	0.68	0.52	0.87	.88
95% CI	0.31-1.49	0.33-0.82	0.34-2.23	
ER				
No. of injuries	6/26	15/112	7/28	
Injury incidence[d]	0.87	0.50	0.64	.68
95% CI	0.40-1.89	0.30-0.82	0.31-1.33	
IR				
No. of injuries	2/21	24/126	2/19	
Injury incidence[d]	0.37	0.66	0.32	.85
95% CI	0.10-1.35	0.44-0.98	0.09-1.16	

[a]CI, confidence interval; ER, external rotation; IR, internal rotation.
[b]Strength deficit ≥1 standard deviation above average (ie, dominant arm stronger than nondominant arm).
[c]Strength deficit ≤1 standard deviation below average (ie, dominant arm weaker than nondominant arm).
[d]Per 1000 pitches.

for major injury was 4.6 (95% CI, 1.4-15.0) relative to the other pitchers (P = .02). Preseason strength deficits for the other strength tests were unrelated to risk for major injury (P = .40-.99).

Injury Risk Analysis: Other Factors

Injury incidence was not different (P = .33) between varsity pitchers (RR, 0.61; 95% CI, 0.40-0.95), junior varsity pitchers (RR, 0.74; 95% CI, 0.36-1.52), and freshman pitchers (RR, 0.17; 95% CI, 0.03-0.94). Higher volume pitchers (1 SD above average = >512 pitches per season) tended to have a higher injury prevalence than did the other pitchers (7/25 vs 21/141, respectively; P = .08). However, there was no difference in injury incidence between high-volume pitchers and the other pitchers (respective injuries per 1000 pitches: 0.4 [95% CI, 0.19-0.83] vs 0.69 [95% CI, 0.44-1.05]; P = .33). Six of 32 pitchers who threw an above-average number of pitches per game (>75) sustained injuries compared with 22 of the remaining 134 pitchers (P = .75). The injury incidence was also not different (P = .17) between pitchers with >75 pitches per game (0.37; 95% CI, 0.17-0.81) and the remaining pitchers (0.69; 95% CI, 0.46-1.04).

DISCUSSION

The Role of ROM Deficits in Injury Risk

On the basis of previous research, it was hypothesized that loss of IR ROM[12] and loss of total ROM[16] might be associated with increased injury risk. However, this was not the case in the present study of adolescent pitchers. Paradoxically, injury incidence was higher in pitchers with no loss of IR ROM (n = 31) compared with pitchers with more than 20° loss of IR ROM (n = 25). A possible explanation is that pitchers with no loss of IR ROM have had inadequate prior exposure to pitching and that their musculoskeletal systems have not properly adapted to the pitching motion. In this regard, it is notable that the adaptive loss of IR ROM in pitchers is apparent at an early age and is of a similar magnitude in high school pitchers (13°),[13] college pitchers (11°),[8] and professional pitchers (12°).[6,16] The average IR ROM loss in the present study (10°) is in line with these previous values.

In a prospective study of high school baseball players, Shanley et al[12] found that subsequently injured players had a preseason IR ROM loss of 12°, whereas players who were uninjured had an IR ROM loss of only 7° (P = .04). The risk for injury for players with IR ROM loss of 25° or more was 4.8 times the risk in the remaining players. However, this study included pitchers and nonpitchers, with no differentiation between the two in terms of IR ROM loss, injury incidence, or exposure in terms of throwing volume. Thus, it was unclear if loss of IR ROM was the risk factor or whether pitchers had greater IR loss due to greater throwing demands and that greater exposure to throwing was the cause of injury. For example, high school pitchers are at least twice as likely to be injured than nonpitchers.[3,4] Furthermore, a greater loss of IR ROM has been reported for pitchers compared with position players.[1]

In professional pitchers, Wilk et al[16] found that injury prevalence was not significantly different between players with 20° or more IR ROM loss and the remaining players (odds ratio, 1.9; P = .17). Furthermore, preseason IR

ROM loss was not different between the subsequently injured pitchers (12.9°) and the uninjured pitchers (11.3°) (P = .46). Thus the presumed association between IR ROM loss and increased injury risk is not supported in the literature. However, Wilk et al did not measure exposure, and therefore odds ratios were based on injury prevalence.

Wilk et al[16] found that professional pitchers with a loss of total ROM of 5° or more had increased injury risk (odds ratio, 2.5; P = .03). Similarly, Shanley et al[12] reported an RR of 3.0 for high school baseball players (pitchers and nonpitchers) with 20° or more total ROM loss, but this was not statistically significant (P = .08), and RR values were smaller at ROM cutoffs other than 20°. In the present study, 24 pitchers had a loss of total ROM of 15° or more (1 SD above the mean), but injury incidence (0.45 injuries/1000 pitches) was not different from pitchers with normal (0.59) or below-normal (0.69) side-to-side differences in total ROM (P = .56). Direct comparisons between the present study and these previous studies are difficult given the differences in study populations and injury reporting. For example, Wilk et al studied professional pitchers, Shanley et al studied adolescent pitchers and nonpitchers, and the present study was limited to adolescent pitchers only. Wilk et al did not report injuries relative to a measure of exposure, Shanley et al reported injuries per 1000 athlete-exposures (games and practices), and the present study reported injuries per 1000 pitches in games.

Previous studies have not prospectively examined the role of PS tightness in injury risk in pitchers. However, in a retrospective study, injured pitchers were found to have greater PS tightness and IR ROM loss than uninjured players.[10] It was unclear if such effects were a cause or a consequence of the injury. In the present study, there was no indication that PS tightness was a risk factor for injury. Injury incidence was 0.89 injuries/1000 pitches for pitchers with greater-than-average PS tightness compared with 0.57 and 0.40 for pitchers with normal and below-normal posterior shoulder deficits (P = .21).

The Role of Strength Deficits in Injury Risk

We hypothesized that strength imbalances would be related to injury risk. Specifically, on the basis of the observations of Trakis et al,[13] we hypothesized that greater IR strength on the dominant versus nondominant side, and weakness in supraspinatus and scapular retraction on the dominant versus nondominant side, would increase the risk for injury. This was clearly not the case with respect to IR and scapular retraction strength (Table 4). However, in agreement with the retrospective findings,[13] there was a trend for preseason supraspinatus weakness to be associated with increased risk for upper extremity injury (RR, 3.6; P = .09). In fact, preseason supraspinatus weakness significantly increased the risk for major injuries (>3 missed games), with an RR of 4.58. This is also consistent with the results of Byram et al,[2] who examined the role of preseason shoulder strength on subsequent injury in professional pitchers. Lower strength scores on the dominant arm in ER and the supraspinatus were associated with increased risk for shoulder injuries requiring surgery. However, there was no measure of exposure in that study. Thus, differences in study population (professional vs high school), quantification of strength (absolute vs relative to nondominant arm), and measure of injury (prevalence vs incidence) make it difficult to compare the studies. Despite the disparities between the present study and the studies of Trakis et al and Byram et al, all 3 studies point to a relationship between supraspinatus weakness and injury risk. Of note, supraspinatus weakness has previously been reported in professional pitchers using the same instrumentation and measurement technique as used in the present study.[6] This weakness was attributed to subclinical pathologic changes. On the basis of the present results, preseason supraspinatus strengthening may be indicated for pitchers with significant weakness (≥20%)

Absolute strength was unrelated to injury risk, but strength was rapidly increasing from year to year in these adolescent athletes, in line with maturation. Therefore, the relationship between absolute strength and injury risk is confounded by age and maturation in this study.

It is important to point out that the pitchers in this study had a relatively low pitching volume. The average number of pitches per game was <50, with the maximum being 110. The 2010 Little League Baseball Regulations recommend a limit of 105 pitches per game for 17- and 18-year-olds and 95 per day for 15- and 16-year-olds.[17] Only 5% of pitchers in this study exceeded these limits in terms of average pitches per game throughout the season. Furthermore, pitches per game averaged fewer than half of these recommended limits for 62% of pitchers. Thus, the generalizability of the results to injuries in high-volume pitching populations may be somewhat limited. In this study, there was only a trend for high-volume pitchers to have a higher injury prevalence than the other pitchers (28% vs 15%, respectively, P = .08). Poor pitching mechanics and the types of pitches thrown are potential risk factors that were not addressed in this study.

The use of 3 different testers for strength and ROM measurements was an unavoidable limitation. However, pitchers tested on more than 1 occasion were always tested by the same tester who performed the initial test. The testers had extensive experience in performing these tests on baseball pitchers[8,13,15] and have previously reported the reliability and validity of the measurements.[9,14,15]

CONCLUSION

There was no indication that excessive loss of IR or total ROM increased the risk for shoulder and elbow injury in these high school pitchers. Preseason supraspinatus weakness appeared to increase the risk for major injuries (>3 missed games). Supraspinatus strengthening in at-risk pitchers is warranted.

REFERENCES

1. Brown LP, Niehues SL, Harrah A, Yavorsky P, Hirshman HP. Upper extremity range of motion and isokinetic strength of the internal

and external shoulder rotators in major league baseball players. *Am J Sports Med*. 1988;16(6):577-585.
2. Byram IR, Bushnell BD, Dugger K, Charron K, Harrell FE Jr, Noonan TJ. Preseason shoulder strength measurements in professional baseball pitchers: identifying players at risk for injury. *Am J Sports Med*. 2010;38(7):1375-1382.
3. Collins CL, Comstock RD. Epidemiological features of high school baseball injuries in the United States, 2005-2007. *Pediatrics*. 2008;121(6):1181-1187.
4. Krajnik S, Fogarty KJ, Yard EE, Comstock RD. Shoulder injuries in US high school baseball and softball athletes, 2005-2008. *Pediatrics*. 2010;125(3):497-501.
5. Lintner D, Mayol M, Uzodinma O, Jones R, Labossiere D. Glenohumeral internal rotation deficits in professional pitchers enrolled in an internal rotation stretching program. *Am J Sports Med*. 2007;35(4):617-621.
6. Magnusson SP, Gleim GW, Nicholas JA. Shoulder weakness in professional baseball pitchers. *Med Sci Sports Exerc*. 1994;26(1):5-9.
7. Meister K, Day T, Horodyski M, Kaminski TW, Wasik MP, Tillman S. Rotational motion changes in the glenohumeral joint of the adolescent/Little League baseball player. *Am J Sports Med*. 2005; 33(5):693-698.
8. Mullaney MJ, McHugh MP, Donofrio TM, Nicholas SJ. Upper and lower extremity muscle fatigue after a baseball pitching performance. *Am J Sports Med*. 2005;33(1):108-113.
9. Mullaney MJ, McHugh MP, Johnson CP, Tyler TF. Reliability of shoulder range of motion comparing a goniometer to a digital level. *Physiother Theory Pract*. 2010;26(5):327-333.
10. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. *Am J Sports Med*. 2006;34(3):385-391.
11. Reinold MM, Wilk KE, Macrina LC, et al. Changes in shoulder and elbow passive range of motion after pitching in professional baseball players. *Am J Sports Med*. 2008;36(3):523-527.
12. Shanley E, Rauh MJ, Michener LA, Ellenbecker TS, Garrison JC, Thigpen CA. Shoulder range of motion measures as risk factors for shoulder and elbow injuries in high school softball and baseball players. *Am J Sports Med*. 2011;39(9):1997-2006.
13. Trakis JE, McHugh MP, Caracciolo PA, Busciacco L, Mullaney M, Nicholas SJ. Muscle strength and range of motion in adolescent pitchers with throwing-related pain: implications for injury prevention. *Am J Sports Med*. 2008;36(11):2173-2178
14. Tyler TF, Nahow RC, Nicholas SJ, McHugh MP. Quantifying shoulder rotation weakness in patients with shoulder impingement. *J Shoulder Elbow Surg*. 2005;14(6):570-574.
15. Tyler TF, Roy T, Nicholas SJ, Gleim GW. Reliability and validity of a new method of measuring posterior shoulder tightness. *J Orthop Sports Phys Ther*. 1999;29(5):262-269.
16. Wilk KE, Macrina LC, Fleisig GS, et al. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *Am J Sports Med*. 2011;39(2):329-335.
17. Zaremski JL, Krabak BJ. Shoulder injuries in the skeletally immature baseball pitcher and recommendations for the prevention of injury. *PM R*. 2012;4(7):509-516.