Muscle Strength and Range of Motion in Adolescent Pitchers With Throwing-Related Pain

Implications for Injury Prevention

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Background: A high prevalence of throwing-related shoulder and elbow pain has been documented in adolescent baseball pitchers.

Hypothesis: Pitchers with a history of throwing-related pain will have weakened dominant-arm posterior shoulder musculature and greater dominant-arm glenohumeral total range of motion (ROM) loss compared with pitchers without throwing-related pain.

Study Design: Controlled laboratory study.

Methods: Twenty-three adolescent pitchers (age 15.7 ± 1.4 years) were tested. Twelve pitchers had throwing-related pain in the prior season and were currently symptom-free, while the remaining 11 pitchers had no such history of pain. Internal and external rotation ROM and muscle strength (lower trapezius, middle trapezius, rhomboids, latissimus dorsi, supraspinatus, internal rotators, external rotators) were measured bilaterally. Dominant versus nondominant differences in ROM and strength were compared between pitchers with and without throwing-related pain.

Results: As a whole, the group of 23 pitchers had a loss of internal rotation ROM (13° ± 10°, $P < .001$) and gain in external rotation ROM (11° ± 10°, $P < .001$) on the dominant versus nondominant arm, with no effect on total ROM (2° ± 7° loss, $P = .14$). There was no difference in bilateral comparison of total ROM between pitchers with and without throwing-related pain. Dominant versus nondominant muscle strength was lower ($P < .05$) for the pain group versus nonpain group for the middle trapezius (7% ± 19% vs 22% ± 12%) and supraspinatus (–4% ± 27% vs 14% ± 14%) and higher ($P < .05$) for the internal rotators (19% ± 14% vs 6% ± 12%).

Conclusion: Throwing-related pain in this population may be due to the inability of weakened posterior shoulder musculature to tolerate stress imparted on it by adaptively strengthened propulsive muscles.

Clinical Relevance: Selective posterior shoulder strengthening may be indicated in rehabilitative and injury prevention programs for adolescent pitchers.

Keywords: pitchers; strength characteristics; throwing-related pain

The high prevalence of injury and self-reported pain in young baseball players has perpetuated the great attention that this population has received in the literature. In a cohort of baseball pitchers aged 9 to 14 years, 32% complained of shoulder pain and 26% complained of elbow pain at some point during the season.[15] McFarland and Ireland[17] cite throwing-related injuries as the leading cause of upper extremity overuse injury in the adolescent athlete. Despite high injury prevalence and greater understanding of throwing biomechanics, there remains debate over the causes of throwing pain and respective treatment strategies.

In their 3-part series, Burkhart et al[4-6] defined glenohumeral internal rotation deficit (GIRD) as the start of a cascade leading to dead arm syndrome in the overhead

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thrower. However, GIRD, with a concomitant increase in glenohumeral external rotation range of motion (ROM) has been consistently documented in the dominant, compared with nondominant, shoulder of healthy baseball players.[1,7,8,10,18] In support of Burkhart's theory, without equal gain in external rotation ROM, GIRD has been associated with pathologic changes in the overhead thrower at the collegiate and semiprofessional levels.[21,27]

In addition to the shift observed in shoulder ROM in the throwing athlete, side-to-side differences in rotator cuff muscle strength have been reported in adult baseball pitchers. Specifically, increased muscle strength of the internal rotators without concomitant external rotator strength increases (or with baseline strength deficits) has been documented.[9,13,16,19,20,24,31] The extent to which these ROM and strength adaptations are apparent in adolescent pitchers has not been established. Furthermore, the relationship between ROM and strength adaptations and throwing-related pain in adolescent pitchers is not known. Therefore, the purpose of this study was twofold: (1) to establish if ROM and strength adaptations are evident in the dominant arm of adolescent pitchers, and (2) to investigate if strength and ROM adaptations differ between pitchers with and without a history of throwing-related shoulder and elbow pain. It was hypothesized that pitchers with throwing-related pain would be weaker in the posterior shoulder musculature and have a greater loss of total ROM compared with pitchers without throwing-related pain.

MATERIALS AND METHODS

Participants

After the fall baseball season had ended, 25 starting pitchers from local high schools and town baseball leagues completed a questionnaire regarding injuries, pain with pitching, and playing statistics for that season. The following information was recorded: (1) the number of games pitched, (2) the number of games pitched during which the player had shoulder or elbow pain, (3) the magnitude of the worst pain the player pitched with during that season (0 = no pain, 10 = worst imaginable pain), (4) the percentage of practices in which the player had shoulder or elbow pain (not including postexercise muscle soreness), (5) whether the player had pain with nonbaseball activities, (6) whether the pitcher thought that pain affected performance or mechanics in any game, and (7) if the player sustained any injuries that required medical treatment and resulted in missed time. Two pitchers were excluded from testing because they had a shoulder or elbow injury during the season that required medical treatment and resulted in missed time. Because specific strength and ROM rehabilitation exercises were prescribed for these players, this would have confounded postseason strength and ROM measures. Therefore, 23 male pitchers (age, 15.7 ± 1.4 years; height, 176 ± 10.2 cm; weight, 71.6 ± 12.9 kg) underwent postseason strength and ROM testing. No participants had any pain at the time of the examination or with any of the testing.

Range of Motion Testing

Three alternating readings of glenohumeral external rotation ROM and internal rotation ROM were made in the supine position using the methods described by Mullaney et al,[19] with some modifications for scapular stabilization with internal rotation ROM as noted below. Standard goniometric landmarks were used. The participant was positioned in 90° of shoulder abduction with 90° of elbow flexion and the forearm in neutral. For external rotation ROM, the shoulder was passively rotated until an end-range position was attained. No overpressure, only the weight of the arm, was provided at end range. For internal rotation ROM, the same landmarks were used; however, the tester provided a posteriorly directed force over the coracoid and humerus, allowing no scapular protraction or anterior tipping to influence the measurement. Manual scapular stabilization has been shown to improve both intra- and interrater reliability for the measurement of shoulder internal rotation ROM via goniometry.[2] Once again, only the weight of the arm, not overpressure, was used to achieve a stable end point. A second tester stabilized the stationary arm of the goniometer. Both testers were blinded to arm dominance and results of the questionnaire. Before testing, a coin was flipped to determine which extremity would be examined first.

Strength Testing

Strength testing was performed using a handheld dynamometer (Nicholas Manual Muscle Tester, Lafayette Instruments, Lafayette, Indiana). The handheld dynamometer was calibrated in accordance with the manufacturer's recommendation before testing. The reliability and validity of handheld dynamometry in the assessment of upper extremity strength has been satisfactorily documented.[8,16,23,28,30] Compared with isokinetic examination, the use of handheld dynamometry for muscle-strength testing has been found to be more sensitive in identifying shoulder rotational weakness in subjects with impingement.[30] Moreover, it has been used extensively in the examination of strength in baseball players.[8,16,19,33] The order of testing was as follows: lower trapezius, middle trapezius, rhomboids, latissimus dorsi, supraspinatus, internal rotators, and external rotators. For testing via handheld dynamometry, 3 readings were recorded for each muscle or muscle group tested. A break test was performed in each position with the dynamometer positioned just proximal to wrist. The strength testing methods previously used for collegiate pitchers[19] were replicated here, with some modifications for testing internal and external rotators. The subject was positioned prone for testing of the lower trapezius, middle trapezius, rhomboids, and lattisimus dorsi. The shoulder was abducted to 145° with full glenohumeral external rotation for the lower trapezius test. Middle trapezius strength was tested by placing the shoulder in 90° of abduction with full external rotation. The rhomboids were tested with the shoulder in 90° of abduction and full internal rotation. Finally, with the arm at the side and in neutral rotation, lattisimus dorsi strength was tested.

The supraspinatus was tested with the subject in a sitting position and the shoulder elevated to 90°, 30° anterior to the frontal plane, and in full internal rotation (empty can test). The subject was instructed to grasp the treatment table to provide trunk stability. The internal and external rotators were tested as described by Tyler et al,[30] with the subject seated and strapped in an isokinetic testing chair (Biodex System 3, Biodex Medical Systems, Shirley, New York) for trunk stabilization. The shoulder was placed in 90° of external rotation and abduction. For the external rotators, the tester provided stabilization at the medial epicondyle of the elbow while executing the break test. When testing the internal rotators, stabilization was provided at the lateral epicondyle of the elbow.

Data Analysis

Paired *t* tests were used to test for differences between the dominant and nondominant arms for strength and ROM for the entire group of pitchers regardless of prior throwing-related pain. This was done to provide an overall description of any adaptations occurring with baseball in this sample of young pitchers. Dominance effects were compared between pain groups using mixed-model analysis of variance. For the ROM group (pain versus no pain) by direction (internal rotation ROM deficit versus external rotation ROM deficit), analysis of variance was used. An independent *t* test was used for between-group comparison of total ROM deficit. On the basis of previous work,[3] we estimated that an 11° difference in loss of total ROM between the pain and nonpain groups could be detected ($P < .05$) with 80% power.

Because physical maturity is varied and rapidly changing in adolescent athletes, it was necessary to normalize strength measures. Therefore, strength in the dominant arm was normalized to strength in the nondominant arm (ie, percentage difference between arms, referred to as dominance effect). These dominance effects were then compared between players with and without prior throwing-related pain using a muscle (7 different tests) by group (pain vs no pain) analysis of variance. Post hoc pairwise comparisons of between-group differences for particular muscle tests were applied using the least significant difference approach. It was hypothesized that posterior shoulder strength would be weaker in the pitchers with prior throwing-related pain. Based on the between-subject variability in posterior shoulder strength dominance effects in collegiate baseball pitchers tested in a previous study,[19] it was estimated that a difference in strength (normalized to the nondominant side) of 17% between pain and nonpain groups could be detected ($P < .05$) with 80% power. For example, if supraspinatus strength were 5% stronger on the dominant versus the nondominant side for 1 group, and 22% stronger on the dominant versus nondominant side for the other group, the difference in the dominance effect would be 17%. Adjusting the *P* value for the number of possible between-group comparisons (7) would have increased the estimated effect size to >22%. Given the likelihood of a type 2 error with such an approach, no adjustment was made. Thus the between-group comparisons in this study are subject to the increased possibility of a type 1 error.

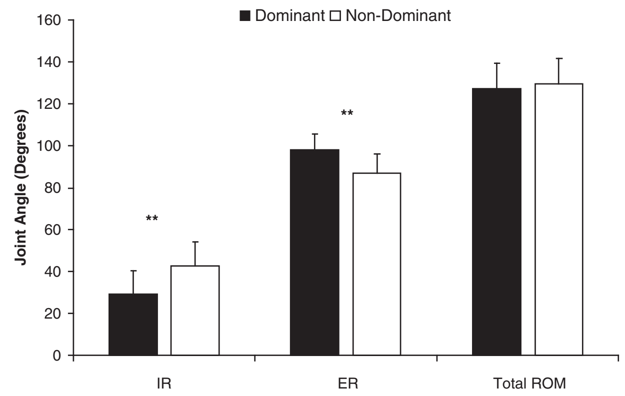

Figure 1. Dominant versus nondominant differences in glenohumeral internal rotation (IR) and external rotation (ER) range of motion (ROM) and total ROM. Mean ± standard deviation displayed. **Difference between the dominant and nondominant sides ($P < .001$).

RESULTS

Strength and ROM Adaptations for the Entire Sample

The pitchers had less internal rotation ROM (13° ± 10°, $P < .0001$) and greater external rotation ROM (11° ± 10°, $P < .0001$) on the dominant versus nondominant arm, with no difference in total ROM (2° ± 7° loss, $P = 0.22$) (Figure 1). Pitchers had greater strength on the dominant side for the lower trapezius, middle trapezius, latissimus dorsi, internal rotators (all $P < .01$) and the external rotators ($P < .05$) (Figure 2). There was no significant difference between the dominant and nondominant sides for strength of the rhomboids ($P = .4$) and the supraspinatus ($P = .08$). Strength of the external rotators was 67% ± 10% of the internal rotators on the dominant side versus 72% ± 15% on the nondominant side ($P = .15$).

Prevalence of Prior Throwing-Related Pain

Twelve of the pitchers reported having throwing-related pain during the previous season. They pitched in 12 ± 9 games (range, 2-40) and reported having pain in 11 ± 9 games (range, 1-15). Pain intensity was 4 ± 2 out of 10 (range, 2-6); only 1 pitcher had pain during nonbaseball activities. Only 4 pitchers had pain during practice (averaging 26% of practices; range, 2%-75%). Three pitchers thought that pain affected their performance or mechanics. The pitchers with prior pain did not differ from those without prior pain in age (15.7 ± 1.3 years vs 15.8 ± 1.6 years; $P = .91$) or in the number of games pitched that season (12 ± 9 games vs 10 ± 6 games; $P = .54$).

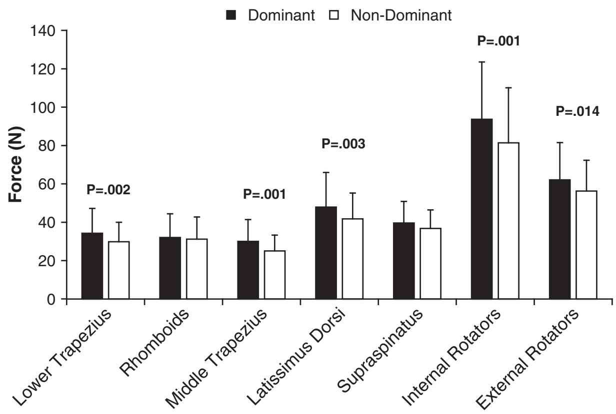

Figure 2. Dominant versus nondominant differences in strength. Mean ± standard deviation displayed. Differences between the dominant and nondominant sides shown with respective *P* values.

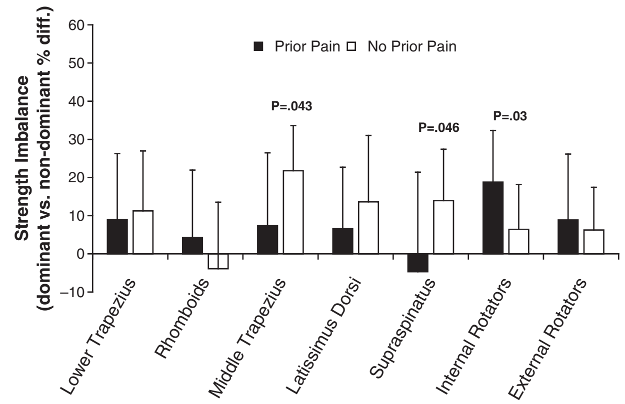

Figure 3. Strength imbalances ([dominant – nondominant]/nondominant × 100) in pitchers with and without throwing-related pain in the prior season. Mean ± standard deviation displayed. Strength imbalance for middle trapezius and supraspinatus was smaller for pitchers with prior pain; strength imbalance for internal rotators was greater for the pitchers with prior pain.

Strength and ROM Comparisons Between Pitchers With and Without Prior Pain

For ROM deficits, the group by direction interaction was not significant (P = .25); for the pitchers with prior pain versus those without prior pain, internal rotation ROM loss was 12° ± 12° versus 15° ± 6° (P = .49), external rotation ROM gain was 8° ± 11° versus 14° ± 8° (P = .14), and total ROM loss was 4° ± 7° versus 0° ± 8° (P = .28).

For strength dominance effects, there was a significant muscle by group interaction ($P < .001$); the percentage difference in strength between the dominant and nondominant sides was smaller for pitchers with prior pain compared with those without prior pain for the supraspinatus (–5% ± 26% vs 14% ± 13%; P = .046) and middle trapezius (7% ± 19% vs 22% ± 12%; P = .043) (Figure 3). By contrast, the difference in strength in the internal rotators between the dominant and nondominant sides was greater for pitchers with prior pain compared with the pitchers with no prior pain (19% ± 14% vs 6% ± 12%; P = .03) (Figure 3). Therefore, the pitchers with prior pain had greater relative strength of the internal rotators compared with the players without prior pain and lower relative strength of the supraspinatus and middle trapezius. Strength dominance effects were not different between players with and without prior pain for the other strength tests (lower trapezius 9% ± 17% vs 11% ± 16% [P = .74], rhomboids 4% ± 18% vs –4% ± 17% [P = .28], latissimus dorsi 7% ± 16% vs 14% ± 17% [P = .33], and external rotators 9% ± 17% vs 6% ± 11% [P = .67]) (Figure 3). Strength of the external rotators was 67% ± 9% of the internal rotators for the pitchers with prior pain and 67% ± 10% for the pitchers with no prior pain (P = 0.95).

DISCUSSION

The distractive force created during pitching places great eccentric stress on the shoulder external rotators, supraspinatus, scapular retractors, and scapular depressors. Examination by MRI of the rotator cuff of amateur baseball players reveals significant T2 elevation in the supraspinatus and external rotator musculature up to 96 hours after pitching.[34] Moreover, electromyographic (EMG) analyses have demonstrated high supraspinatus, trapezius, and external rotator muscle activity during the follow-through phase of pitching.[11,14] The increased dominant-arm internal rotation strength is likely a function of the high demand placed on this muscle group with pitching.[19] Internal rotation strength dominance during pitching may increase the tensile stress on the posterior rotator cuff and scapular stabilizers during follow-through. Of the muscle strength adaptations observed in the overhead thrower, increased dominant-shoulder internal rotator strength has been documented most consistently. A throwing shoulder internal rotator dominance effect has been reported in overhead throwers at the professional level,[8,9] collegiate level,[22] and high school level.[13] This study corroborates those findings.

Dominant-shoulder external rotator weakness and a lower dominant-shoulder external to internal rotator strength ratio has been reported in professional pitchers,[8,31] but not in high school pitchers.[13] In the present study, the external rotators were stronger on the dominant side and the external to internal rotator strength ratio was not different between the dominant and nondominant arms. Pitching experience may explain the disparity in external rotator strength relative to internal rotator strength in adolescent versus adult pitchers. Supraspinatus weakness has been reported in the collegiate pitcher[19] and inconsistently in professional pitchers.[8,16] In the current study, there was no side-to-side difference in supraspinatus strength.

In this study, 12 pitchers (52%) complained of throwing-related elbow or shoulder pain throughout the previous season. This prevalence is comparable with studies with larger sample sizes of youth pitchers.[12,15] Lyman et al[15] reported that 47% of pitchers aged 9 to 14 years had shoulder and/or elbow pain over 2 spring baseball seasons. In a sample of 73 pitchers (average age, 17 years), Grana and Rashkin[12] found that 58% of subjects had throwing-related pain throughout a single season. The present data demonstrate that pitchers with prior pain had greater relative strength of the internal rotators compared with the pitchers without prior pain, and concomitant lower relative strength of the supraspinatus and middle trapezius. This indicates that throwing-related pain is associated with an imbalance between the propulsive internal rotators and muscles responsible for deceleration and stabilization of the shoulder during pitching. Given the small number of pitchers investigated, the observed between-group strength differences might reflect a type 1 error, and the results should be viewed as preliminary. However, the magnitudes of the significant between-group strength differences were in line with the estimated effect size. It was estimated, based on prior work, that the sample size in this study was sufficient to detect a 17% difference in posterior shoulder strength (normalized to the nondominant side) between groups. The significant between-group differences were 19% for the supraspinatus and 15% for the middle trapezius. The 13% between-group difference in internal rotator strength was the only other statistically significant difference; all other differences were <9%.

It has been previously theorized that increased strength of the dominant internal rotators without strengthening of the rotator cuff muscles and the scapular stabilizers puts the shoulder at risk for injury.[32] The current data support this theory with respect to throwing-related pain in adolescent pitchers. We hypothesize that, secondary to high demands on the internal rotators and the repetitive eccentric stress placed on the supraspinatus, external rotators, and scapular stabilizers with throwing, certain pitchers tend to develop a strength imbalance over time. It is plausible that weakened posterior shoulder musculature decelerating an arm propelled by overdeveloped anterior musculature leads to posterior muscle and connective tissue injury. This could lead to contracture of posterior capsular soft tissue, total ROM loss, and possibly more significant injury. This subject warrants further examination in a prospective study with a larger sample than was used here.

External rotator strength relative to the nondominant side was not significantly different between pitchers with and without prior pain. However, it is noteworthy that the position used in our study to test middle trapezius strength, prone with the shoulder abducted to 90° and in full glenohumeral external rotation, elicits high EMG activity in the teres minor, infraspinatus, the middle deltoid, and posterior deltoid.[29] Furthermore, isotonic exercise performed in a similar test position, prone with the shoulder abducted to 100° with full external rotation, was found to elicit higher EMG activity in the supraspinatus, middle deltoid, and posterior deltoid than 6 other exercises designed to improve shoulder external rotator strength.[26] The test position used for middle trapezius strength in this study may be a more general way to characterize posterior shoulder strength deficits in this population.

Examination of the group as a whole revealed no deficit in total ROM, as has been reported in professional pitchers.[10,32] Moreover, total ROM measurements were not different between the pitchers with and without prior pain. Based on the previously demonstrated relationship between total ROM loss and shoulder injury in collegiate and semiprofessional pitchers,[21,27] it was hypothesized that pitchers with prior pain would have a loss of total ROM compared with the other players. Before data collection, based on previous work,[3] it was estimated that an 11° difference in loss of total ROM between the pain and nonpain groups could be detected ($P < .05$) with 80% power. Post hoc analysis corroborated that estimate, indicating that there was 80% power to detect a 9° between-group difference at $P < .05$. This effect size is in line with the standard error of measurement for the internal rotation ROM measurement used in this study, which was reported to be 8°.[2] For pitchers with prior pain, total ROM was on average 4° less on the dominant side while the average difference was 0° for pitchers without prior pain (between-group difference not significant). If we considered the standard error of the measurement (8°) to be a threshold for a clinically significant loss of total ROM, then 6 pitchers had a clinically significant loss of total ROM and 5 of those had prior throwing-related pain (χ^2; $P = .08$ for between-group difference). A larger sample is needed to determine if a clinically significant loss of total ROM is a factor in pitchers with throwing-related pain. In any case, this study indicates that dominant shoulder strength imbalance may precede any total ROM loss as the first step toward future pathologic changes in pitchers.

Potential weaknesses of the current study are that the dependent variable is self-reported pain and that our test group was composed of athletes who did not seek medical attention or miss playing time throughout the previous season. Excluding pitchers requiring medical attention was an important aspect of the study because the purpose was to investigate physical characteristics that may be the underlying cause of future, more serious shoulder or elbow pathology. Olson et al[25] found that young pitchers (average age, 18 years) who pitched with throwing-related pain were significantly more likely to go on to need shoulder or elbow surgery than pitchers who did not. With regard to self-reported pain, end-of-season recall bias is an inherent limitation in this type of study but it is also possible that if players were asked about throwing-related pain during the season, they may have been reluctant to admit to a medical professional that they were playing with pain. Another limitation of this study was that the only measure of physical maturity was age. While there was no between-group difference in age, the pain group may have differed from the other pitchers in Tanner stage or pitching experience.

CONCLUSION

Adaptive responses in ROM and strength were apparent in the dominant upper extremity of the adolescent pitchers in this study. Twelve of 23 adolescent baseball pitchers (52%) had throwing-related shoulder and/or elbow pain during the season before data collection. These pitchers had greater strength of the internal rotators (defined by the difference between the dominant and nondominant side) than the players without prior pain. Pitchers with prior pain also had weaker relative supraspinatus and middle trapezius strength than the pitchers without prior pain. Glenohumeral internal rotation deficit and total ROM were not different between the pitchers with and without prior pain. These data suggest that throwing-related pain in adolescent pitchers may be due to the inability of the posterior shoulder musculature to tolerate stress imparted by adaptively strengthened propulsive muscles. Selective posterior shoulder strengthening may be indicated for injury prevention and rehabilitative programs directed to adolescent pitchers.

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