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Deficiencies in Pitching Biomechanics in Baseball Players With a History of Superior Labrum Anterior-Posterior Repair

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Background: Baseball pitchers who undergo superior labrum anterior-posterior (SLAP) repair often have trouble returning to their previous level of performance. While the reason is often assumed to be diminished shoulder range of motion or other mechanical changes, differences in pitching biomechanics between baseball pitchers with a history of SLAP repair and pitchers with no injury history have not been studied previously.

Hypothesis: The primary hypothesis was that compared with the control group, the SLAP group would exhibit compromised shoulder range of motion (external rotation and horizontal abduction) and internal rotation torque during pitching.

Study Design: Controlled laboratory study.

Methods: Pitching biomechanics were compared retrospectively between a group of 13 collegiate and professional pitchers with a history of a SLAP tear and a control group of 52 pitchers with no history of surgery; groups were matched by age, height, weight, and pitch velocity. Data were collected with an automated 3-dimensional motion analysis system while participants threw fastballs from the windup. Biomechanics of the shoulder (horizontal abduction and external rotation), elbow (flexion, extension velocity, and flexion torque), and body (stride length, shoulder horizontal adduction, and forward trunk tilt) were compared between the 2 groups. For each variable, a Student *t* test was used at an α level of .05.

Results: Pitchers in the SLAP group exhibited significantly less shoulder horizontal abduction (10.0° ± 13.2° vs 21.0° ± 11.7°, respectively; P = .013) and shoulder external rotation (168.3° ± 12.7° vs 178.3° ± 7.3°, respectively; P = .016) than those in the control group. In addition, players in the SLAP group pitched with a more upright trunk, demonstrated by a less forward trunk tilt at the instant of ball release (30.2° ± 6.3° vs 34.4° ± 6.6°, respectively; P = .048).

Conclusion: Pitchers with a history of SLAP repair produce less shoulder horizontal abduction, shoulder external rotation, and forward trunk tilt during pitching than do pitchers with no history of injury.

Clinical Relevance: To facilitate normal pitching mechanics, shoulder external rotation and horizontal abduction at 90° should be primary objectives in surgical repair and rehabilitation after SLAP repair. In addition, pitchers should work with their pitching coaches to ensure proper forward trunk tilt.

Keywords: shoulder; labral tear; external rotation; abduction

Superior labral lesions affecting the origin of the long head of the biceps tendon were first reported in overhead-throwing athletes by Andrews et al[1] in 1985. The term "SLAP" (superior labrum anterior-posterior) tear was coined and classified by Snyder et al[15] in 1990. Over the past decade, there has been a reported 458% increase in the number of SLAP repairs, from 4 per 100,000 surgeries in 2002 to 22.3 per 100,000 in 2010.[13] The American Board of Orthopaedic Surgery determined that SLAP repairs make up 10% of all shoulder surgeries and are now the second most common among all arthroscopic procedures.[17]

The surgical repair of unstable SLAP tears is indicated in baseball pitchers who have failed nonoperative treatment and wish to continue overhead throwing. These superior labral tears may occur near the time of ball release, as the biceps contracts to both resist glenohumeral distraction and decelerate elbow extension.[1,9] Alternatively, the bicipital-labral complex may tear because of a "peel-back" mechanism as the abducted shoulder externally rotates during the arm-cocking phase in throwing.[2] Shepard et al[14] measured in vitro strength of the biceps-labral complex during both the distal force and peel-back

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mechanisms and concluded that SLAP lesions most likely occur from the repetition of both peel-back and distal forces.[11]

The focus of the repair is to restore the patient's preinjury anatomy, promote healing of the labrum, and not overtension the glenohumeral ligaments. Extra tension in the ligaments may resolve shoulder instability but could negatively affect a pitcher's ability to obtain the shoulder external rotation and horizontal abduction necessary to throw effectively. Rehabilitation after SLAP repair employs a stepwise progression protocol that begins on the day after surgery.[18] The repair is protected with no active shoulder external rotation, abduction, or extension along with no biceps strengthening during the first 6 weeks. In addition, external rotation must be performed cautiously to avoid peeling back of the repaired labrum and is gradually progressed from 10° to 15° of external rotation in the scapular plane during the first 2 weeks. Throwing does not begin in rehabilitation until approximately 6 months after surgery. Therefore, surgical repair and the rehabilitation required for successful healing after SLAP repair may lead to unwanted limitations of shoulder external rotation and horizontal abduction. Furthermore, pitchers with a history of shoulder surgery might modify their elbow or body biomechanics to compensate and protect their surgically repaired shoulder. However, no previous study has examined throwing biomechanics after surgical repair and rehabilitation of SLAP tears. Thus, the purpose of this study was to determine if there are differences in pitching biomechanics between pitchers with a history of SLAP repair and those in a matched, uninjured control group.

The primary hypothesis of this controlled laboratory study was that, compared with the control group, the SLAP group would exhibit compromised shoulder range of motion (horizontal abduction and external rotation) and internal rotation torque during pitching. There were 2 secondary hypotheses: (1) pitchers with a history of SLAP repair would have alterations in elbow mechanics (flexion, extension velocity, and flexion torque) possibly caused by compensation for the shoulder, and (2) pitchers with a history of SLAP repair would exhibit mechanical symptoms associated with "holding back" from injury—-namely, a shorter stride length, increased maximum horizontal adduction (ie, "leading with the elbow"), decreased forward trunk tilt at the instant of ball release, and decreased forward trunk tilt at the instant of maximum shoulder internal rotation.

MATERIALS AND METHODS

This study was approved by the institutional review board of St Vincent's Health System. A review of the biomechanics database at the American Sports Medicine Institute identified 634 collegiate and professional male baseball pitchers tested between 2000 and 2014. Pitchers were included in the SLAP group if they were healthy at the time of testing and had undergone SLAP repair by any surgeon at least 1 year before their biomechanical testing. One year between SLAP repair and biomechanical testing was selected as a conservative minimum for this study because pitchers typically return to competition about 9 months after isolated SLAP repair.[18] Of the 634 pitchers in the database, 13 met the inclusion criteria for the SLAP group. These pitchers were evaluated in the American Sports Medicine Institute's biomechanics laboratory a mean of 22 months (range, 13-47 months) after SLAP repair. A control group was identified from the database, consisting of 52 pitchers with no history of surgical repair to the throwing elbow or shoulder. The pitchers in the control group were selected at a 4:1 control-to-case ratio, with efforts to match the SLAP group in pitched ball velocity, level of play, height, weight, and age at the time of biomechanical analysis.

An a priori power analysis was conducted to determine this study's ability to detect significant differences. According to previously published data, the SDs of our 2 primary outcome variables, maximum external rotation and horizontal abduction, for healthy adult pitchers were 10° and 11°, respectively.[5] The power analysis revealed that for an α of .05 and a β of .80, the current study design could detect significant differences between the 2 groups of 10° of external rotation or 10° of horizontal abduction, with 12 patients in the SLAP group matched to 48 controls. Based on our biomechanical and clinical expertise, smaller differences would have limited practical relevance.

Biomechanical Testing

After completing the informed consent and history forms, each participant changed into skin-tight (eg, spandex or Lycra) shorts, socks, and athletic shoes. Anthropometric measurements were taken, and reflective markers were then attached to the participant. Twenty-three reflective markers were attached: 4 to a hat worn on the head and bilaterally on the acromion process, lateral elbow epicondyle, ulnar styloid, greater trochanter, lateral femoral epicondyle, lateral malleolus, and second metatarsal. Additional markers were placed on the medial elbow epicondyle, forearm, radial styloid, and third metacarpal of the throwing arm as well as the heel of the lead foot.

After markers were applied, the participant was instructed to conduct his normal warm-up routine of stretching and nonthrowing drills. Each participant concluded his warm-up by throwing a nonspecified number of pitches in the indoor testing facility. Once the participant indicated that he was ready to begin, data for 10 fastball pitches were collected for analysis. Pitches were thrown from a portable pitching mound (Athletic Training Equipment Co) toward a strike zone ribbon located over a home plate 18.5 m (60.5 ft) from a pitching rubber. Ball speed was recorded with a radar gun (Stalker Sports Radar). An automated digitizing motion analysis system (Eagle System, Motion Analysis Corp) used 8 synchronized cameras to measure the location of the reflective markers attached to the participant at a rate of 240 Hz. Three-dimensional motion was calculated using the direct linear transformation method as described by Wood and Marshall.[19] Kinematic variables (angular displacement and velocity) and kinetic values (joint force and torque) at the

TABLE 1
Participant Characteristics[a]

	SLAP Group (n = 13)	Control Group (n = 52)	*P* Value
Velocity, m/s	35.7 ± 2.0	35.8 ± 2.0	.85
Level			>.99
Collegiate, no. (%)	8 (62)	33 (63)	
Professional, no. (%)	5 (38)	19 (37)	
Height, cm	188.1 ± 5.6	187.8 ± 6.5	.87
Weight, kg	93.6 ± 10.8	90.4 ± 9.3	.35
Age, y	23.2 ± 3.5	20.9 ± 2.0	.034[b]

[a]Values are expressed as mean ± SD. SLAP, superior labrum anterior-posterior.
[b]Significant difference ($P < .05$) between groups.

TABLE 2
Shoulder Biomechanics[a]

	SLAP Group	Control Group	*P* Value
Shoulder horizontal abduction at foot contact, deg	10.0 ± 13.2	21.0 ± 11.7	.013[b]
Maximum shoulder external rotation, deg	168.3 ± 12.7	178.3 ± 7.3	.016[b]
Maximum shoulder internal rotation torque, N·m	87.8 ± 12.5	87.5 ± 17.8	.96

[a]Values are expressed as mean ± SD. SLAP, superior labrum anterior-posterior.
[b]Significant difference ($P < .05$) between groups.

shoulder and elbow joints were calculated as previously described.[4,5,7]

Statistical Analysis

All statistical tests were performed using JMP 10 (SAS Institute Inc). Level of play was compared between pitchers in the SLAP group and those in the control group using a Fisher exact test, while group age, height, mass, and ball velocity were compared using independent Student *t* tests. For the 3 hypotheses, mean values for kinematic and kinetic variables were computed for each participant and then compared between the SLAP group and the control group using independent-samples Student *t* tests. Before analysis, the α level was set as .05 for every test.

RESULTS

The participant anthropometrics, ball velocity, and level of play for the SLAP and control groups are presented in Table 1. Pitchers in the SLAP group were significantly older ($P = .034$) than those in the control group by approximately 2 years. There were no statistically significant differences between groups in height, mass, ball velocity, or level of play.

TABLE 3
Elbow Biomechanics[a]

	SLAP Group	Control Group	*P* Value
Maximum elbow extension angular velocity, deg/s	2324 ± 268	2280 ± 254	.60
Maximum elbow flexion torque, N·m	46.8 ± 10.1	44.1 ± 12.8	.42
Maximum elbow flexion angle, deg	107.8 ± 13.4	101.3 ± 12.7	.13

[a]Values are expressed as mean ± SD. SLAP, superior labrum anterior-posterior.

TABLE 4
Holding Back Mechanics[a]

	SLAP Group	Control Group	*P* Value
Stride length, % height	82.9 ± 6.3	82.3 ± 5.2	.74
Maximum shoulder horizontal adduction, deg	17.7 ± 6.7	16.8 ± 7.3	.66
Forward trunk tilt angle at ball release, deg	30.2 ± 6.3	34.4 ± 6.6	.048[b]
Forward trunk tilt angle at maximum shoulder internal rotation, deg	44.1 ± 8.2	47.7 ± 8.3	.17

[a]Values are expressed as mean ± SD. SLAP, superior labrum anterior-posterior.
[b]Significant difference ($P < .05$) between groups.

Shoulder biomechanics during pitching are presented in Table 2. Pitchers in the SLAP group had less horizontal abduction at foot contact ($P = .013$) and less maximum external rotation ($P = .016$). However, there was no difference in internal rotation torque between groups.

Biomechanics of the elbow are presented in Table 3. There were no significant differences in elbow biomechanics between the SLAP and control groups.

Variables that, in our experience, are associated with "holding back" from injury were compared between groups and are presented in Table 4. Pitchers in the SLAP group pitched more upright, exhibiting less forward trunk tilt at ball release ($P = .048$). There were no other significant differences in stride length, maximum horizontal adduction angle, or forward trunk tilt at maximum shoulder internal rotation (during follow-through).

DISCUSSION

As hypothesized, shoulder biomechanics were compromised in pitchers with a history of SLAP repair. In particular, such pitchers exhibited less external rotation and horizontal abduction. Chalmers et al[3] also reported reduced maximum shoulder external rotation in pitchers with a history of SLAP repair (however, their finding was not statistically different, which is likely due to their low sample size). Decreased external rotation in pitching after SLAP repair is consistent with previous cadaveric research that demonstrated that anchors placed anterior to the long head of the biceps tendon during SLAP repair can limit shoulder external rotation.[10] The most common complication after symptomatic type II SLAP repair has been reported as refractory postoperative stiffness in forward flexion and external rotation, reported at 8.5%.[10] It is important to note, however, that an overall statistically significant improvement in external rotation at 90° of abduction has been reported between preoperative and postoperative measurements, although a comparison with uninjured controls was not performed.[10] Furthermore, there has been a reported increased risk of postoperative stiffness after SLAP repair with concomitant rotator cuff repair.[6,11] In this study, a statistically significant decrease in maximum shoulder external rotation was found when comparing pitchers who previously underwent SLAP repair to uninjured, matched controls.

As well, SLAP repair may affect elbow function because the surgery involves fixation of the detached origin of the long head of the biceps tendon in the shoulder. The biceps is a 2-joint muscle that provides flexion torque at the elbow.[7] Thus, SLAP repair may, in theory, compromise the ability to generate elbow flexion torque to decelerate elbow extension during pitching. Elbow biomechanics might also be compromised as compensation. That is, a pitcher with a shoulder injury and surgery might consciously or subconsciously alter his mechanics to shift some stress from the shoulder to the elbow. However, the hypothesis that elbow biomechanics would be different for pitchers with SLAP repair was not confirmed. There was no difference in maximum elbow flexion torque, maximum elbow flexion angle, or maximum elbow extension velocity.

While some pitchers successfully return after injury, others have difficulty returning to their previous ball velocity and performance. This is frustrating for the athlete and his team. Biomechanists and pitching coaches often observe that pitchers returning from injury look like they are "holding back." Based on our clinical experience in the biomechanics laboratory, pitchers in this situation demonstrate a shorter stride, less forward trunk tilt, and/or "pushing the ball." "Pushing the ball" is a colloquial expression for throwing with increased shoulder horizontal adduction and increased elbow flexion. As hypothesized, pitchers in the SLAP group exhibited less forward trunk tilt than did those in the control group at ball release. However, there were no differences between the 2 groups in stride length or horizontal adduction.

Of interest to pitching coaches is the decreased forward trunk tilt in the SLAP group. Chalmers et al[3] also reported a slight deficiency in forward trunk tilt for pitchers with a history of SLAP repair (although their finding was not statistically different, which was likely due to their low sample size). Thus, when working with a pitcher with a history of SLAP repair, a coach may want to emphasize drills to ensure proper forward trunk tilt through ball release. For example, some pitching coaches employ a towel drill for a pitcher who stands too upright in his delivery. In this drill, the pitcher simulates pitching but with a towel in his hand instead of a baseball. The pitcher tries to snap the towel at the coach's hand in front of him, and the coach gradually backs up to lengthen the pitcher's trunk lean.

Return to play for elite overhead athletes has been reported at only 57%.[12] The inability to return to overhead activity has been correlated with tearing of the posterior rotator cuff, which is the corresponding lesion that occurs in internal impingement.[8,16] The inability to return to play also occurs when the athlete cannot regain his previous level of performance. While this study analyzed the pitching mechanics of athletes who returned to full-effort pitching after SLAP repair, this study did not analyze the pitching mechanics of those who could not return. Therefore, no causal link to failure to return to play based on pitching mechanics can be made.

The main limitation of this study was the assumption that differences between pitchers in the SLAP group and those in the control group were caused by the SLAP repair and rehabilitation. It is conceivable that before their SLAP tears, pitchers in the SLAP group possessed different pitching biomechanics from those in the control group. Ideally, a better designed study would have been to quantify the pitching biomechanics of pitchers in the SLAP group before their injury as well as after recovery, but biomechanical data before the SLAP injury were not available. Another limitation was the relatively small sample size of the SLAP group. Despite the limited sample size, several significant differences were found. However, with more participants, other differences might have become significant. While all biomechanics testing was performed at the American Sports Medicine Institute, athletes underwent SLAP repair at various institutions. Therefore, these athletes did not have a single surgeon performing the repair or a uniform rehabilitation protocol. There may be differences in the SLAP repair technique and rehabilitation as well as variations in concomitant shoulder injuries and treatment.

In conclusion, understanding common deficiencies in pitching mechanics after SLAP repair can hopefully lead to improved surgical techniques, rehabilitation, and pitching instruction for more successful outcomes. The value of this study was the confirmation of theoretical deficiencies in pitching mechanics for pitchers with a history of SLAP repair. The decreased shoulder external rotation and horizontal abduction should be of particular concern for sports medicine surgeons and physical therapists, as this position is essential for pitchers and can be compromised by excessive tensioning of the glenohumeral ligaments associated with nonanatomic SLAP repair. Physical therapy should encourage early return of range of motion, particularly passive and active external rotation with 90° of abduction.

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