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CLINICAL FEATURE
ORIGINAL RESEARCH

Acute changes in glenohumeral range-of-motion following in-season minor league pitching starts

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Abstract

Background. Asymmetric glenohumeral range-of-motion (ROM) between the throwing and non-throwing arms of overhead athletes has been well described in the literature. Thresholds of internal rotation (IR) loss have been associated with throwing arm injury in baseball players. Acute changes in shoulder ROM following an individual pitching appearance remain poorly understood. *Objectives:* To determine the acute change of external rotation (ER), IR, and total arc-of-motion (TAM) in minor league starting pitchers immediately following an in-season starting pitching appearance. *Methods.* Nine minor league starting pitchers participated in the study with data collected for 22 individual starts. IR, ER and TAM were measured in the throwing shoulder and non-throwing shoulder at three time points for each appearance: before, immediately following, and at 24 hours following the pitching appearance. *Results.* In the throwing arm, IR significantly decreased (49.4 vs 46.0, $p = 0.037$) immediately after pitching, and ER significantly increased immediately following an appearance (150.7 vs 153.6, $p = 0.030$) and at 24 hours (150.7 vs 154.0, $p = 0.028$). No difference was detected in throwing arm TAM and IR at 24 hours, or TAM immediately following an appearance. *Conclusions.* Minor league pitchers demonstrate the dynamic glenohumeral ROM changes after starting appearances of increased ER and diminished IR with maintenance of TAM. At 24 hours, the observed loss of IR had resolved, whereas the gains in ER remained present. Our study supports the need to further assess the acute changes of glenohumeral ROM in pitchers, and the association of acute glenohumeral ROM change with the development of pathologic ROM profiles and injury.

Keywords:

Range-of-motion, baseball, shoulder, GIRD

History

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Introduction

The throwing arm in many elite level pitchers demonstrates a glenohumeral joint range-of-motion (ROM) profile of increased external rotation (ER) with decreased internal rotation (IR), while maintaining the total arc of motion (TAM) compared to the non-throwing arm [1-5]. These adaptations are considered advantageous for pitchers, as maximal ER during the cocking phase of the pitching motion permits a longer arc of rotation for IR angular acceleration and consequently maximizes pitch velocity [6].

Glenohumeral ROM in the throwing arm of overhead athletes is dynamic and has been shown to change acutely in response to a single pitching episode [7-9]. Several authors have identified pathologic profiles of glenohumeral ROM loss that may develop in response to pitching [6,10-13]. Pathologic glenohumeral ROM includes both total arc of motion deficits and glenohumeral internal rotation deficits (GIRD). TAM deficits and GIRD are believed to alter normal pitching kinematics and are risk factors for shoulder and elbow injuries in pitchers [6,10,11,14-17].

Most glenohumeral ROM literature is descriptive in nature and captures an overhead athlete's profile at only one point in time [2-5,11,18-22]. Several studies prospectively assessed the changes to glenohumeral ROM that occur in pitchers following participation in competitive baseball. These reports focus on changes in glenohumeral ROM over the course of a season [23-25] and immediately following a pitching performance [7-9]. The results of these studies have been variable. As such, the natural history of acute glenohumeral ROM changes, and the process by which maladaptation develops and potentially resolves is poorly understood.

Only three studies have investigated how a single pitching episode acutely changes glenohumeral ROM. Of these three studies, two were conducted in a cohort of professional pitchers during spring training [1,8,9]. The remaining cohort included collegiate pitchers with data collected during in-season competition [7]. The differences in the setting and level of competition between these cohorts are relevant and have likely contributed to the differences in the conclusions drawn between these studies. For example, in spring training

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games, the pitching appearances are generally shorter outings (fewer pitches) and occur in athletes that are not yet in peak physical shape in comparison to regular season games. Additionally, collegiate pitchers likely do not generate as much stress on the throwing shoulder during the season as professional pitchers as the peak pitch velocities are lower and the collegiate season includes fewer games with more rest in between appearances.

The current prospective study uniquely assesses glenohumeral ROM changes in minor league, professional pitchers following in-season pitching appearances. The specific purpose of the study was to compare pre-gram measurements of glenohumeral IR, ER, and TAM at 90° of abduction with measurements obtained immediately following a pitching appearance and at 24 hours following the pitching appearance. We hypothesized that immediately following a pitching appearance, the throwing shoulder of professional pitchers would demonstrate a gain in ER, loss of IR, and maintenance of TAM, and that these changes would be sustained for 24 hours.

Materials and methods

This study was approved by the Wake Forest School of Medicine's institutional review board. All participants in the study provided informed consent following an explanation of the study purposes and methodology.

Study population

A prospective cohort of pitchers on a single minor league professional baseball team were recruited to participate in the study over the course of an entire season (2013). To be eligible for the study, the athlete had to be a starting pitcher during the season with no history of previous shoulder surgery. Nine pitchers, all right-hand dominant, qualified for the study (mean age, 22.9 ± 1.5 years; height, 190.5 ± 5.7 cm; weight, 90.5 ± 12.5 kg).

To control for confounding variables associated with away game performances including consistency with pre-gram and postgame routine, differences in mound heights and slopes, and changes in measurement conditions, only home game starts were used for data collection. Data collection periods were identified prior to the season. The first home series of 4 – 5 consecutive games was identified for each month of the season and selected for data collection. This strategy ensured that the data collection periods were evenly distributed and permitted data collection throughout the entire season. Home game measurements minimized confounding variables by acquiring data in identical settings. Data was collected for 22 unique games and included 9 different starting pitchers participating in the study. The details for the number of starts for each study participant are outlined in Table 1.

Table 1. Number of pitching appearances per participant with number of study participants with the corresponding number of pitching appearances.

	Pitching appearances	Number of participants
	5	1
	4	2
	3	1
	2	1
	1	4
Total	22	9

Technique

The technique for measuring ROM of the shoulders was standardized and consistent with previously published studies [7,9]. Two examiners (the team's head athletic trainer and strength and conditioning coach) performed all measurements with a long-arm bubble goniometer (Medco Supply Company, Inc, Tonawanda, New York). Each measurement was performed twice (once by each examiner). The examiner performing the second measurements remained blinded to the first examiner's results until completing his measurements.

Measurements were recorded with the pitcher supine on a standard treatment table with the shoulder at 90° of abduction and 10° of horizontal adduction (the scapular plane), and with the elbow flexed at 90°. A small foam roll was placed under the arm to ensure the arm maintained position in the scapular plane (Figure 1). The same foam roll was used for each measurement.

Glenohumeral ER and IR were measured with the scapula stabilized by the exam table. Passive limits of ER and IR were determined by a combination of endpoint feel and visualization of compensatory movement of the shoulder girdle by the examiner and determined when motion was stopped. Reference points for measurements were the axis of the goniometer over the olecranon, with 1 arm of the goniometer along the ulnar shaft, and the other arm of the goniometer perpendicular to the floor, as confirmed by the custom bubble inclinometer attachment. Both extremities were measured using the same technique.

Pre-game measurements were performed upon the starting pitchers arrival to the stadium before warming up or stretching. Post-game measurements were performed immediately following a performance and before any icing or cool-down exercises. Twenty-four hour measurements were obtained when the previous days' starting pitcher arrived to the

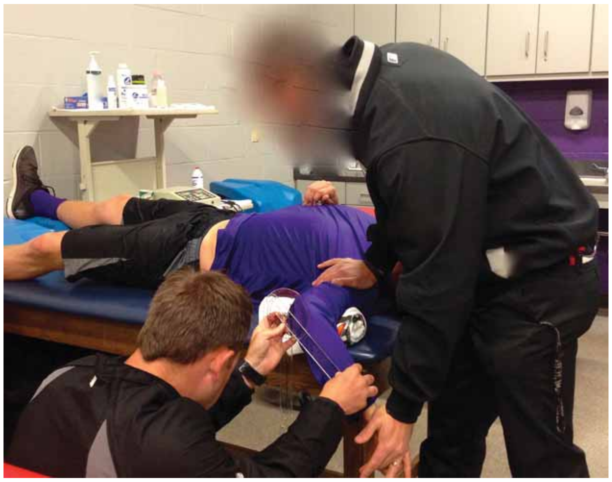

Figure 1. Measurements were obtained in the supine position with the shoulder at 90° of abduction and 10° of horizontal adduction.

Table 2. Range-of-motion before, immediately following, and at 24 hours following pitching appearance[a].

		Pre-Game	Post-Game	24 Hours
IR	TS	49.4° ± 12.0°	46.0° ± 13.9°[b]	47.9° ± 10.1°
	GS	59.7° ± 15.4°	55.0° ± 14.7°[b]	58.1° ± 10.2°
ER	TS	150.7° ± 11.2°	153.6° ± 7.9°[b]	154.0° ± 7.2°[b]
	GS	140.1° ± 13.6°	139.3° ± 13.7°	142.7° ± 12.7°
TAM	TS	200.2° ± 13.2°	199.7° ± 11.2°	202.7 ° ± 11.3°
	GS	202.1° ± 13.1°	195.6° ± 11.7°[b]	200.8 ° ± 11.3°

°Degrees.
[a]Data are mean degrees ± standard deviation.
[b]Significant difference ($p < 0.05$).
Abbreviations: ER = External rotationr; GS = Glove-side shoulder; IR = Internal rotation; TAM = Total arc-of-motion; TS = Throwing shoulde.

stadium and before any stretching or conditioning exercises. Per the routine of the team, a copy of the team's pitching chart was used to obtain the number and type of pitches thrown in each start.

The examiners recorded daily measurements and pitch counts during the season on a specific sheet, which included only the study number assigned to the pitcher and month of the start. They remained blinded to all previous measurements. The collectors were not blinded to handedness for practical reasons. All other study team members were blinded to the results.

Per the routine of the team and baseball organization, all pitchers participated in standardized shoulder warm-ups and cool-downs on days of the season that included pitching from a mound. All pitchers were responsible for performing self-directed daily sleeper stretches. Additional manual stretching of the posterior shoulder structures was performed by the athletic trainer if requested by the athlete, or if it was deemed necessary by the athletic training staff.

Data analysis

Descriptive statistics were calculated and all values are expressed as mean and standard deviation of the mean (SD) for throwing arm and non-throwing arm ER, IR, and TAM. Statistical analysis was performed using IBM SPSS Statistics (V19.0.0, IBM, Armonk, NY) and Prism5 (GraphPadSoftware, La Jolla, CA). Throwing data was analyzed using a repeated-measures analysis of variance. When appropriate, a Tukey *post hoc* test was performed. Significance for all tests was set at $p < 0.05$. Each pitching event was treated as a unique pitching event and statistical analysis was performed on all of the starts.

To measure intraobesrver reliability, 10 measurements were repeated on both the throwing and non-throwing arm for internal and ER by each examiner. Intraobserver reliability was then calculated using the Intraclass Correlation Coefficient within a two-way random effects model and demonstrated high reliability ($\alpha = 0.994$, 95% C.I. = 0.986 – 0.998). After demonstrating adequate reproducibility measurements were not repeated 10 times per study subject, but all subjects were measured by two examiners. Each examiner was blinded to the other. Interobserver agreement was calculated using the Krippendorff's alpha statistic. Krippendorff's alpha is a robust statistic that is applicable to any number of coders and self-adjusts to reliability data [26]. For each analysis, 5000 bootstrap samples were used. IR measurements demonstrated high interobserver reliability ($\alpha = 0.84$, 95% C.I. 0.80 – 0.88). ER measurements also demonstrated high interobserver reliability ($\alpha = 0.84$, 95% C.I. 0.790 – 0.88).

Results

The results for pre-game, post-game, and 24 hour post-pitching ER, IR, and total ROM for the throwing and non-throwing shoulder are summarized in Table 2. The average pitch count for all appearances was 91 ± 10 pitches (range: 63–103).

Throwing shoulder

Post-game IR (46.1° ± 14.0°) was significantly decreased compared to pre-gram IR (49.5° ± 12.0°; $p = 0.037$). By 24 hours, IR returned to pre-gram baseline ($p = 0.379$).

Pre-gram ER of the throwing shoulder measured 150.7° ± 11.2°. Post-game measurements, as well as those recorded at 24 hours after throwing, demonstrated significantly greater ER (153.6° ± 7.9°, $p = 0.030$; 154.0° ± 7.2°, $p = 0.028$, respectively) when compared to pre-game ER.

Total ROM of the throwing shoulder did not demonstrate any significant difference immediately after pitching and at 24 hours following pitching when compared to pre-game measurements ($p = 0.799$, $p = 0.242$, respectively).

Non-throwing shoulder

IR and total ROM immediately following the pitching appearance were significantly less than pre-game measurements (56.3° ± 12.0°, $p = 0.003$; and 195.6° ± 11.7°, $p = 0.03$, respectively). At 24 hours following the pitching appearance, there was no difference in IR or total ROM when compared to pre-game measurements ($p = 0.053$, $p = 0.523$, respectively). ER did not demonstrate any significant difference immediately after pitching and at 24 hours following pitching when compared to pre-gram measurements ($p = 0.580$, $p = 0.091$, respectively).

Discussion

The present study demonstrates acute changes in glenohumeral ROM in the throwing shoulder of professional pitchers after competitive game appearances. These results are similar

Table 3. Summarization of studies characterizing the effects of pitching on acute change in range-of-motion in elite baseball pitchers.

Manuscript	Subjects	Setting	Pitch Count	Δ Internal Rotation	Δ External Rotation	Δ Total Arc-of-motion
Rienold et al. [9]	Professional Pitchers	Spring Training	50-60	Post-game: -9.5°[b] 24 hours: -7°[b]	Post-game: -1.2° 24 hours: 0°	Post-game: -10.7°[d] 24 hours: -7.7°[d]
Kibler et al. [8]	Professionals Pitchers	Spring Training	64 (starters) 41 (relievers)	Post-game: -7°[b] 24 hours: -6°[b]	Post-game: 4°[c] 24 hours: -4°[c]	Post-game: -2° 24 hours: -2°
Freehill et al. [7][a]	Collegiate Pitchers	Regular Season	Mean 78	Post-game: -0.5°	Post-game: 7.9°[c]	Post-game: 7.4°[d]
Current study	Professionals Pitchers	Regular Season	Mean 91	Post-game: -3.4°[b] 24 hours: -1.6°	Post-game: 2.9°[c] 24 hours: 3.3°[c]	Post-game: -0.5° 24 hours: 1.6°

[a]Did not assess range-of-motion at 24 hours.
[b]Change in internal rotation was significant in comparison to pre-throwing measurements ($p < 0.05$).
[c]Change in external rotation was significant in comparison to pre-throwing measurements ($p < 0.05$).
[d]Change in total arc-of-motion was significant in comparison to pre-throwing measurements ($p < 0.05$).

to previous studies that have shown dynamic changes in shoulder ROM immediately following pitching (Table 3) [7-9].

Similar to Reinold et al. [9] and Kibler et al. [8], the present study demonstrated IR loss after a pitching appearance; however, our results differed from previous studies in that the observed IR loss resolved by 24 hours [8,9]. Similar to Freehill et al. [7] and Kibler et al., [8], we found that ER increases immediately after pitching, and the gains in ER were still present at 24 hours [8]. Additionally, our results were consistent with results from Kibler et al. [8] in that total ROM did not change following pitching [8], but contrasted with Freehill et al. and Reinold et al. where total ROM increased and decreased respectively [7,9].

Previous studies have not examined acute changes in glenohumeral ROM in context of an isolated pitching event. The reasons for the observed heterogeneity are not clear. Potential uncontrolled factors that may help explain these differences include the timing of the study (Spring Training vs in-season), setting (bullpen session vs live competition), number of pitches thrown, differences in pre-game warm-up routines and post-game stretching protocols, individual pitching mechanics, differences in duration of resting period between pitching appearances, age of the pitchers, and level of competition (collegiate vs professional).

More attention should be focused on the difference in IR loss between the studies conducted during Spring Training and those conducted during the season. Loss of IR, more than any other pathologic ROM profile, has been implicated with injury by what Burkhart described as, "a pathologic cascade that climaxes in the late cocking phase of throwing [6]". During spring training, Reinold et al. [9] and Kibler et al. [8] found that a single pitching appearance resulted in a statistically significant loss of IR both immediately after ($\Delta IR = -9.5°, -7°$; $p < 0.05$, $p < 0.05$), and at 24 hours ($\Delta IR = -7.6°, -6°$; $p < 0.05$, $p < 0.05$) [8,9]. Our results also demonstrated a significant loss to IR immediately following pitching ($\Delta IR = -3.4°$, $p < 0.05$), although at a seemingly smaller magnitude than the results of Kibler et al. [8] and Reinold et al. [9]. At 24 hours, this loss of IR had resolved. These results are similar to those of Freehill et al. who also assessed GH ROM changes following in-season pitching and found no significant IR change in pitchers immediately following an appearance ($\Delta IR = -0.5°$, $p < 0.05$) [7].

The apparent difference in magnitude of acute IR loss seen during Spring Training when compared to in-season appearances could potentially be explained by the conditioning of the posterior rotator cuff muscles that occurs over the course of the season. Multiple authors have previously implicated the resting tension in muscles the rotator cuff contribute to glenohumeral ROM, particularly in the acute setting [1,9]. During Spring Training, the rotator cuff muscles are relatively deconditioned following the inactivity of the off-season. Although the athlete is rested and generally conditioned at the season's start, the arm may not be in "throwing" shape, particularly with regard to the high degree of eccentric muscle activity required by the external rotators of the rotator cuff during the pitching motion [27]. Eccentric exercise in deconditioned muscles acutely increases passive tension; however, with repeated exposure (conditioning), the magnitude of post-exercise stiffness diminishes [28]. Furthermore, Janecki et al. demonstrated that repeated exposure to eccentric exercise not only reduces initial stiffness following exercise, but also decreases the time necessary to return to baseline tension [29]. These previously published findings are consistent with the lack of complete recovery of IR loss at 72 hours following a spring training appearance [8], and the resolution of IR loss by 24 hours seen in our results after an in-season appearance.

The less dramatic loss of IR loss seen in the regular season when compared to the studies conducted during the preseason may better reflect a normal response of the shoulder to the stress of throwing and could potentially be an indicator of overall joint health. Burkhart has described the "dead arm" phenomenon [6,30], which includes a loss of proprioceptive feedback, decreased capsular tension, and increased glenohumeral translation. In this context, sustained GIRD and a subsequent type II SLAP lesion are the root causes of this phenomenon, and the injury has matured to a chronic condition that causes the pitcher pain and diminishes his ability to perform at his peak level. Anecdotally, in our experience working with pitchers, we have identified a more transient "dead arm" phenomenon. The symptoms of the transient "dead arm" are nearly identical to those that Burkhart described, with subjective loss of proprioceptive feedback and loss of command during pitching; however, it occurs in the absence of pain. Additionally, we have found these complaints to arise most frequently at the beginning of each season. Given the similarities in clinical presentation to

Burkhart's "dead arm", this transient "dead arm" phenomenon could potentially be caused by pitching with an acute loss of IR that has not completely resolved from a previous start. The resolution of these complaints as the season progresses supports this hypothesis as our study has demonstrated that the acute loss in IR following a pitching event is not sustained past 24 hours, and that the resolution of the IR loss by 24 hours may indicate a normal, healthy response in the conditioned athlete.

Our study is consistent with previous studies that have demonstrated a gain in ER following a single pitching event [7,8]. In our study, ER remained increased significantly at 24 hours. To our knowledge there is no method of recovery for sustained increases in ER, which is in contrast to sustained IR loss, where a posterior capsular stretching routine throughout the season can help with recovery of IR deficits [31]. Further work should focus on gains in ER, and whether increased ER places the biceps tendon and the superior labrum at potential risk for injury.

Our study also identified acute changes in ROM in the non-throwing shoulder after a starting appearance, specifically a transient decrease of IR and TAM, which resolved by 24 hours. Other studies have also shown altered ROM in non-throwing shoulder after acute pitching episodes and over the course of the season [7,32,33]. The significance of this finding is that our current standard for diagnosing pathologic motion requires comparisons between the throwing and non-throwing shoulders. Bilateral comparisons are clinically necessary and pertinent, especially in the initial evaluation of an injured player. However, given that the non-throwing shoulder ROM may change over the course of a season, we believe that monitoring ipsilateral glenohumeral ROM in pitchers over the course of a season more accurately assesses the response to stress in the throwing shoulder and that it may be beneficial in identifying developing pathology.

Our study is limited by the small study population of nine pitchers with measurements obtained for 22 unique starts; however, we found statistically significant differences despite the small sample size. Minor League Baseball rosters undergo many changes throughout the season. Players are promoted or released throughout the year, miss time with injury, and new players join rosters following the June amateur draft. We were consequently unable to obtain data from the same five starters for each data collection period. In our study, only one pitcher remained in the starting rotation for each month of the season, which limited the number of available pitcher starts. A strength of this data collection method is that our study is more generalizable, as we have demonstrated the phenomena of significant shoulder ROM changes following in-season pitching in a greater number unique study subjects.

Our study analyzed the dynamic response to pitching in starting pitchers to provide greater control of potential confounding factors including: days off between pitching appearances, consistency with conditioning and stretching protocols between appearances, and number of pitches thrown. Relief pitchers have demonstrated differences in both the baseline glenohumeral ROM profile and the degree dynamic change in ROM over the course of a season [8,23]. Exclusion of relief pitchers precluded the analysis of changes in ROM associated with throwing on consecutive days, or "short rest," when pitchers would not have had the time to recover to their baseline pre-gram ROM profile. It may be beneficial for future studies to address the dynamic change in shoulder ROM in response to pitching in a fatigued state (such as the short rest model for relievers), as it is generally assumed that this condition places the pitcher at a greater risk for injury as well as poor performance.

Conclusion

Starting pitchers demonstrate dynamic changes in glenohumeral ROM following an in-season appearance with increased ER and diminished IR, and maintenance of TAM. At 24 hours, the observed loss of IR had resolved, whereas the gains in ER remained present. Studies investigating the acute changes in glenohumeral ROM after pitching have produced heterogeneous results. Our study supports the need to assess factors associated with the development of the pathologic ROM profiles associated with injury in pitchers.

Declaration of interest

MT Freehill is a consultant for Smith & Nephew. The authors have no other relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript apart from those disclosed.

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