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Identifying the underlying mechanisms responsible for glenohumeral internal rotation in professional baseball pitchers

Ryan W. Paul, BS, CSCS[a,b], Brandon J. Erickson, MD[c], Steven B. Cohen, MD[a], Michael G. Ciccotti, MD[a], Michael Hefta, MS, ATC[d], Paul Buchheit, MS, ATC[e], Joseph Rauch, DPT, ATC[e], Shawn Fcasni, MS, ATC[f], Alex Plum, DPT[e], Aaron Hoback, ATC[e], Stephen J. Thomas, PhD, ATC[g,*]

[a]*Department of Orthopaedic Surgery, Rothman Orthopaedic Institute, Philadelphia, PA, USA*
[b]*Hackensack Meridian School of Medicine, Nutley, NJ, USA*
[c]*Department of Orthopaedic Surgery, Rothman Orthopaedic Institute, New York, NY, USA*
[d]*Physical Therapy Institute, Little Rock, AR, USA*
[e]*Philadelphia Phillies, Philadelphia, PA, USA*
[f]*Major League Baseball Umpire Association, New York, NY, USA*
[g]*Department of Exercise Science, Thomas Jefferson University, Philadelphia, PA, USA*

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Background and Hypothesis: Glenohumeral internal rotation deficit has been identified as a significant risk factor for upper-extremity injuries in pitchers across all ages. Humeral retroversion (HR), posterior capsule thickness (PCT), and posterior rotator cuff muscle pennation angle (PA) have been independently associated with internal rotation range of motion (IR ROM); however, these anatomic structures have not been collectively measured in baseball pitchers to determine the underlying mechanisms responsible for IR ROM. Therefore, the purpose of this study was to determine the contributions of HR, PCT, and posterior rotator cuff PA on IR ROM during a preseason evaluation in healthy professional baseball pitchers. The authors hypothesized that HR, PCT, and posterior rotator cuff PA would have a significant contribution to IR ROM.
Methods: This is a cross-sectional study. Healthy professional pitchers from a single organization were recruited at the beginning of the 2021 Major League Baseball Spring Training. Participants received bilateral IR ROM assessment while laying supine with the shoulder at 90 degrees of abduction and the scapula stabilized. Ultrasound imaging was also performed bilaterally to assess HR, PCT, infraspinatus (superficial + deep) PA, and teres minor (superficial + deep) PA. All ultrasound imaging processes were performed utilizing previously published, highly reliable techniques. A stepwise regression was performed, which included both arms to determine the mechanisms of IR ROM.
Results: Overall, 49 pitchers (88 shoulders) with an average age of 22.5 ± 2.2 years were included in the final data analysis. Stepwise linear regression found that only HR and PCT were associated with the preseason IR ROM. There was a moderate relationship between HR and PCT relative to IR ROM ($R = 0.535$, $P < .001$).
Conclusion: HR and PCT were found to be the primary mechanisms responsible for the preseason glenohumeral IR ROM. The posterior rotator cuff was not found to be significantly related to IR ROM. Future research evaluating these anatomic structures longitudinally—both acutely and chronically—will help clinicians optimize ROM management throughout the season. As glenohumeral internal rotation deficit can have harmful effects in baseball pitchers, understanding which anatomic structures are most responsible for IR ROM is important for injury prevention and treatment.

Shoulder and elbow injuries account for about 25% of all injuries in professional baseball players.[3] As glenohumeral internal rotation deficit (GIRD) has been identified as a significant risk factor for upper-extremity injuries in pitchers across all ages, clinicians have implemented treatment strategies to monitor pitchers' internal rotation range of motion (IR ROM) and improve IR ROM when it is lacking with various stretches (sleeper, cross-body adduction,

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*Corresponding author: Stephen J. Thomas, PhD, ATC, Department of Exercise Science, Thomas Jefferson University, 4201 Henry Ave, Philadelphia, PA 19144, USA.
E-mail address: sjthomasatc@gmail.com (S.J. Thomas).
@shoulder_nerd (S.J. Thomas)

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etc.).[11,26,27] While several anatomic structures have been associated with shoulder IR ROM, the precise effect of each of these various structures on IR ROM loss is yet to be determined.

Due to the high eccentric forces required by the posterior rotator cuff to decelerate the pitching shoulder, adaptations to the posterior rotator cuff, specifically of the pennation angle [PA] (defined as the angle between the longitudinal axis of the entire muscle and its fibers) and muscle thickness, are expected in baseball pitchers.[21] However, only 1 study has evaluated the posterior rotator cuff muscles in professional pitchers, showing that PA adaptations of the teres minor may affect the glenohumeral IR ROM.[21] If the infraspinatus and teres minor are fatigued, the posterior capsule will be required to dissipate more of the deceleration forces at the end of IR ROM.[2] This can lead to a loss of elasticity of the posterior capsule, thereby worsening IR.[20] Several research studies have evaluated the posterior capsule thickness (PCT) in youth,[1] high school,[9] collegiate,[10,20,22] and professional[18] baseball players. Across all age groups, the throwing arm has been shown to have a thicker posterior capsule than the nonthrowing arm.[1,9,10,18,20,22]

As for bony contributions, children are born with their humeri retroverted (externally rotated), and throughout development, humeri antevert (rotate internally).[7] However, the stresses of throwing at a young age are believed to halt this anteversion progression at the humeral epiphysis, leaving the throwing shoulder in a retroverted (externally rotated) position relative to the nonthrowing shoulder.[19] With the throwing shoulder retroverted, glenohumeral ROM is shifted toward increased external rotation (ER) and decreased IR.[4,17,18,25]

Posterior rotator cuff architecture, PCT, and humeral retroversion (HR) have all been negatively correlated with IR ROM.[4,10,17,21,22] However, no study has evaluated the posterior capsule, posterior rotator cuff muscles, and HR together to determine their relative contributions to IR ROM. Therefore, the purpose of this study was to evaluate the contributions of posterior rotator cuff PA, PCT, and HR to IR ROM during a preseason evaluation in healthy professional baseball pitchers. The authors hypothesized that HR, PCT, and infraspinatus PA would be strongly correlated with IR ROM.

Materials and methods

Participants

This study was approved by our institutional review board (Thomas Jefferson University IRB #21D.056). Baseball pitchers from a single professional baseball organization who took part in the 2021 Major League Baseball Spring Training were recruited. Players were included if they (1) were pitchers aged 18 years or older, (2) were healthy and eligible for participation in team activities, and (3) had not undergone an upper-extremity surgery within the past year. Pitchers were excluded if they were not participating in team activities or if they had a surgery of the upper extremity within the past year.

Data collection

Pitchers were recruited during the standard-of-care preseason medical screening regardless of the offseason pitching volume. A printed institutional review board form was provided to each pitcher, and the study was verbally explained before consent. Players who agreed to participate received bilateral ultrasound imaging to measure HR, glenohumeral PCT, and PA of the posterior rotator cuff muscles (infraspinatus and teres minor) by a team research consultant (S.J.T.) with over a decade of musculoskeletal ultrasound imaging experience. All ultrasound measurements performed have been previously published with good reliability by the study investigator and validated with the help of a musculoskeletal radiologist.[21–23] A team clinician (P.B.) also measured IR ROM supine with the scapula stabilized and the shoulder at 90 degrees of abduction. A goniometer was used to quantify ROM, with an average of 2 measurements used for data analysis.

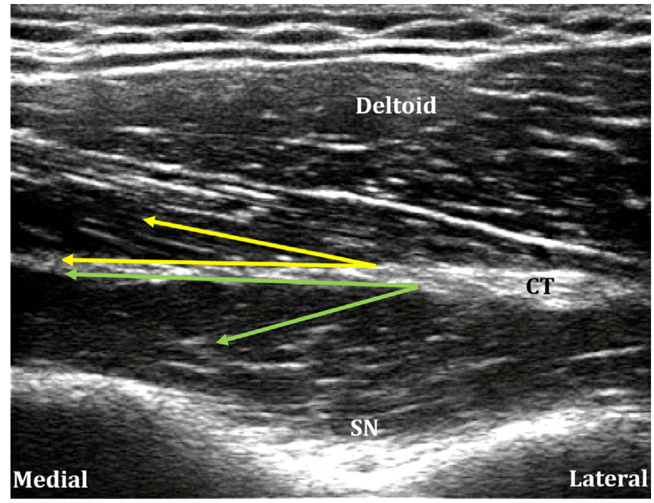

Figure 1 Ultrasound image of the infraspinatus, with ⟵ indicating the superficial infraspinatus pennation angle and ⟵ representing the deep infraspinatus pennation angle. *CT*, central tendon; *SN*, suprascapular notch.

Ultrasound

All ultrasound images were captured with a portable diagnostic ultrasound machine with a 15-MHz linear transducer (Sonosite M-Turbo; Sonosite, Inc., Botthell, WA, USA). PA of the infraspinatus and teres minor was measured with a previously described ultrasound technique.[21] To view the PA (superficial and deep to the central tendon) of the infraspinatus, the ultrasound probe was initially positioned parallel to the spine of the scapula. The probe was then moved inferiorly, with slight adjustments to clearly visualize the muscle fascicles. The PA was indicated by muscle fascicles running into the deep aponeurosis or central tendon. Once the PA (the angle between muscle fascicles and central tendon) was clearly visible, the image was saved (Fig. 1). Three images were taken on both shoulders.

To evaluate PA (superficial and deep to the central tendon) of the teres minor muscle, pitchers were asked to isometrically adduct their shoulder against resistance so the contracted teres major muscle could be easily identified. The ultrasound probe was then positioned between the teres major and the infraspinatus. Once the PA was clearly visible, the image was saved. Three images were taken for both shoulders.

PCT was assessed using a previously described, reliable, and validated ultrasound technique.[22,23] Participants were seated in a chair with their forearm resting on their leg in order to standardize glenohumeral rotation between participants. The ultrasound probe was placed on the posterior shoulder to visualize the rotator cuff, humeral head, and glenoid labrum. Once the structures were clearly visible, the image was saved. Three images were saved on both shoulders.

HR was also quantified utilizing a previously described, reliable, and validated ultrasound technique.[13,23] Participants were asked to lay supine with their shoulder at 90 degrees of abduction and their elbow at 90 degrees of flexion. The ultrasound probe was placed on the anterior shoulder, perpendicular to the long axis of the humerus. The researcher then rotated the

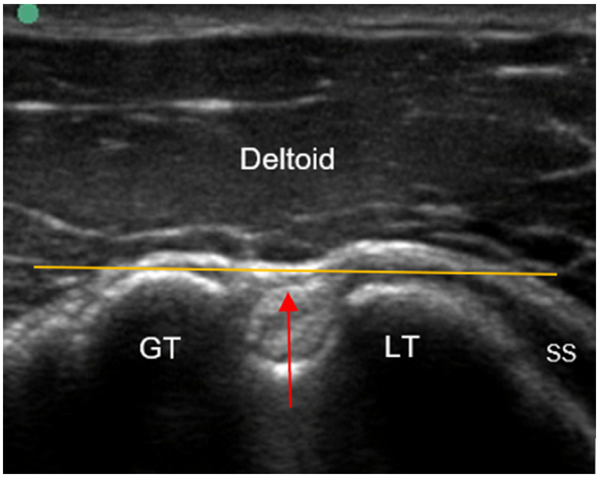

Figure 2 Ultrasound imaging of the bicipital groove for humeral retroversion measurement. The humerus is rotated until the superficial aspects of the bicipital groove (*yellow line*) are horizontal, and then the forearm inclination angle is measured representing humeral retroversion. *GT*, greater tuberosity; *LT*, lesser tuberosity; *SS*, subscapularis.

subject's humerus until the bicipital groove was positioned perpendicular to the treatment table and until the greater and lesser tubercles became parallel with the horizontal grid of the ultrasound screen. Once the bicipital groove was positioned properly, an assisting researcher (R.W.P.) placed a digital inclinometer along the ulnar side of the forearm (Fig. 2). This forearm inclination angle was used to represent HR. This process was repeated 3 times, with an average of the 3 measurements used for data analysis.

Image analysis

Ultrasound images were imported to the Image J software (National Institutes of Health, Bethesda, MD, USA) in order to quantify PCT, as well as infraspinatus and teres minor PA. The posterior capsule was identified between the humeral head and the rotator cuff and immediately lateral to the tip of the labrum. For both the infraspinatus and teres minor, superficial and deep PA were quantified as the angle of the superficial and deep muscle fascicles, respectively, inserting into the central tendon.

Statistical analysis

Any shoulder without complete data was excluded from data analysis. Fifty-two healthy pitchers (104 shoulders) were recruited and received bilateral shoulder ultrasound imaging. One pitcher was removed for not receiving a range-of-motion assessment, and 2 players were removed for having poor ultrasound image quality bilaterally, while 4 dominant and 6 nondominant shoulders were unilaterally excluded for having poor ultrasound image quality of the teres minor. Mean and standard deviations were calculated for the continuous demographic variables while percentages were calculated for categorical demographic variables. A stepwise linear regression was performed to determine which variables were associated with IR ROM. Correlation coefficients (R) of 0.00-0.19 were considered inexistent, 0.20-0.39 as weak, 0.40-0.59 as moderate, 0.60-0.79 as strong, and 0.80-1.00 as very strong. Statistical significance was set at 0.05.

Table I
Bilateral assessment of humeral retroversion, posterior capsule thickness, posterior rotator cuff muscle pennation angles, and internal rotation range of motion.

Variable	Dominant	Nondominant
Humeral retroversion (°)	76.8 ± 9.5	58.4 ± 12.2
Posterior capsule thickness (mm)	2.7 ± 0.6	2.2 ± 0.4
Superficial infraspinatus PA (°)	11.3 ± 2.7	12.1 ± 2.6
Deep infraspinatus PA (°)	15.6 ± 3.6	15.9 ± 2.9
Superficial teres minor PA (°)	10.0 ± 2.7	10.3 ± 2.6
Deep teres minor PA (°)	13.3 ± 2.6	13.4 ± 2.6
Internal rotation ROM (°)	46.6 ± 9.2	58.8 ± 10.3

PA, pennation angle; *ROM*, range of motion.

Results

Overall, 49 pitchers (88 shoulders) were included in the final data analysis. The average age of the included pitchers was 22.5 ± 2.2 years, and 73% of them were right-hand dominant. The mean and standard deviation of all variables are presented in Table I.

Stepwise linear regression found that only HR and PCT are associated with the preseason IR ROM, with HR being the primary contributor (Table II). There was a moderate relationship between HR and PCT relative to IR ROM (R = 0.535, $P < .001$). Superficial infraspinatus PA, deep infraspinatus PA, superficial teres minor PA, and deep teres minor PA were not related to IR ROM (all $P > .05$).

Discussion

The roles of HR, the posterior capsule, and the posterior rotator cuff have challenged clinicians, with no studies conducted that evaluate all these structures to determine their relative contributions to IR ROM. The authors' hypothesis was partly confirmed as HR was the main contributor to preseason IR ROM, while the posterior capsule also played a smaller role; however, the posterior rotator cuff was not significantly related to the preseason IR ROM.

Humeral retroversion

HR is the main contributor to IR ROM, which in isolation would decrease IR ROM by 1 degree while increasing ER ROM by 1 degree. However, this one-to-one relationship is not observed *in vivo*, as the surrounding soft tissue is suggested to play a significant role as well. Several studies published in 2002 suggested HR may contribute significantly to the observed bilateral differences in shoulder IR and ER ROM in baseball players.[5,15,17] Reagan et al[17] performed a study (n = 54) with collegiate baseball players, finding a significant, moderate relationship between HR and IR ROM ($P = .003$, R = 0.403) in all players and a nonsignificant, weak relationship (R = 0.370, $P = .069$) when looking at only pitchers. Our study confirms that HR is the main contributor to IR ROM, with a regression coefficient of -0.502. However, a regression coefficient of only -0.502 indicates that there are other structures also responsible for IR ROM loss. Soft-tissue structures likely also contribute to IR ROM loss as well, as supported by the impact of PCT in model 2 of our regression analysis.

Posterior capsule thickness

Several authors have tried to isolate the effects of soft-tissue structures by accounting for HR in a calculation often termed HR-corrected GIRD or soft-tissue GIRD (clinical GIRD + bilateral difference in HR).[8,18,21,24] Players with increased HR are at an increased risk to develop soft-tissue GIRD, potentially due to a greater stress

Table II
Determination of the included and excluded variables for the internal rotation range of motion model, with correlation coefficients of the entered models.

Model	Variables	Beta (β)	*P* value	R (R^2)	*P* value
Entered	HR (°)	−0.408 (−0.559 to −0.258)	**.001**	0.502 (0.252)	**.001**
Entered	HR (°) + PCT (mm)	HR: −0.382 (−0.532 to −0.232) PCT: −3.350 (−6.659 to −0.040)	HR: **.001** PCT: **.047**	0.535 (0.286)	**.001**
Excluded	Superficial infraspinatus PA (°)	0.148	.122		
Excluded	Deep infraspinatus PA (°)	0.091	.325		
Excluded	Superficial teres minor PA (°)	−0.013	.893		
Excluded	Deep teres minor PA (°)	−0.048	.605		

HR, humeral retroversion; *PCT*, posterior capsule thickness; *PA*, pennation angle.
Statistically significant relationships are in bold. Beta (β) values are presented as β (95% confidence interval) for the stepwise regression. Both R and R^2 values are presented, with R^2 values in parentheses.

placed on the posterior shoulder during the follow-through phase of pitching with increased HR.[8,14,23] As an increase in HR will decrease the IR ROM, this will cause shortening of the deceleration phase within the throwing motion, ultimately putting more stress on the posterior shoulder soft-tissue structures.[14,23] Since the throwing shoulder has been shown to have a thicker posterior capsule than the nonthrowing shoulder, clinicians have speculated that PCT may play a role in limiting IR ROM.[1,9,10,18,20,22] A recent published study currently supports this belief, with the amount of posterior capsule hypertrophy moderately related (R = 0.40) to the soft-tissue GIRD (ie, HR-corrected GIRD) in 45 elite pitchers.[16] Data from this current study further support this belief, as PCT was the only other variable to enter the stepwise linear regression model with HR. It is possible that some of the impact PCT has on IR ROM may be associated with the previously established relationship with HR.[23] In this current study, by performing a stepwise linear regression, we were able to control for this concomitant increase in HR and saw that the effects of PCT on IR ROM were still significant.

Posterior rotator cuff

A recent study evaluated the effects of dominant-arm infraspinatus and teres minor muscle architecture on IR ROM before a 60-pitch simulated game, right after the simulated game, and 5 days following the simulated game in 10 college-aged pitchers.[12] Deep infraspinatus PA was significantly related to acute IR ROM changes (R = 0.528), while stepwise linear regression determined that measuring deep infraspinatus PA, superficial infraspinatus PA, and muscle thickness of the teres minor led to the strongest relationship to IR ROM loss and recovery after a bout of pitching (R = 0.647).[12] The results of the current study along with the findings of Mirabito et al[12] suggest that posterior rotator cuff architecture is more important for evaluating the acute changes in IR ROM instead of the baseline, chronic IR ROM. Furthermore, it is unclear how the posterior rotator cuff architecture changes throughout the season and if workload plays a role in these changes.

Clinical recommendations

When evaluating the contributions of bony and soft-tissue structures to IR ROM, clinicians need to consider both acute and chronic adaptations. HR and PCT appear to be the primary chronic contributors to IR ROM. Once skeletal maturity has occurred, HR will not change.[7] In addition, the posterior capsule consists of passive connective tissue which requires repetitive loading over time to adapt according to Davis's law.[6] However, the posterior rotator cuff muscle is a dynamic tissue that has been shown to acutely change stiffness characteristics and PA immediately following acute bouts of eccentric loading and pitching, respectively. Hence, IR ROM at the beginning of the preseason training will likely maximize the evaluation of chronic adaptations by minimizing the effects of acute pitching volume. However, daily IR ROM measurements during the season will be impacted by both acute and chronic adaptations, with the impact of the posterior rotator cuff diminishing throughout the rest period between pitching bouts.

Limitations

There are several limitations to this study. First, we utilized a cross-sectional study design, so the effects of these anatomic structures to changes in IR ROM over time could not be determined. Second, our study cohort only included professional baseball pitchers, so the findings of this study may not be generalizable to other patient populations. Third, there are several other ways to evaluate the posterior capsule and posterior rotator cuff that we were not able to perform due to feasibility. It would be interesting to include magnetic resonance imaging in the analysis to help with clinical evaluation, as well as ultrasound elastography so that tendon and capsule mechanical properties could be assessed. Fourth, offseason pitching volume was not quantified, which may affect preseason ultrasound measurements. Fifth, only HR and not glenoid retroversion was included in this study. However, glenoid retroversion has been shown to only differ 3 degrees bilaterally compared to a 17-degree difference in HR bilaterally in professional baseball pitchers.[5] Lastly, this assessment was performed at the beginning of spring training, so limitations in IR ROM were minimal. However, we believe this may instead be viewed as a strength of our study, as this helped isolate the chronic mechanisms of IR ROM as opposed to acute mechanisms.

Conclusions

HR and PCT were found to be the primary mechanisms responsible for preseason glenohumeral IR ROM. The posterior rotator cuff was not found to be significantly related to IR ROM. The posterior rotator cuff may instead contribute more to GIRD following pitching. Future research evaluating these anatomic structures longitudinally—both acutely and chronically—will help clinicians optimize ROM management throughout the season. As GIRD can have harmful effects in baseball pitchers, understanding which anatomic structures are most responsible for IR ROM is important for injury prevention and treatment.

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Michael Ciccotti is a board or committee member of the American Orthopaedic Society for Sports Medicine, the Major League Baseball Team Physicians Association, and the Orthopaedic Learning Center.

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