Effect of Forearm Position on Glenohumeral External Rotation Measurements in Baseball Players

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Background: Alterations in glenohumeral internal rotation (GIR), glenohumeral external rotation (GER), and the total arc of motion (TAM) have been linked with increased injury risk in the shoulder and elbow. These motions have been routinely measured with the forearm in neutral rotation (GIRN, GERN, TAMN). GER capacity appears to be especially important. The throwing motion, however, requires forearm pronation as GER occurs to achieve optimal cocking (GERP). No previous studies have evaluated GERP to determine GER capacity or pronated TAM (TAMP) values.

Hypothesis: There would be significant differences between GERN and TAMN and between GERP and TAMP.

Study Design: Cross-sectional.

Level of Evidence: Level 3.

Methods: Sixty asymptomatic male Minor League Baseball players (32 pitchers, 28 position players) participated in the study and were tested on the first day of spring training. Passive range of motion measurements were recorded using a long-arm bubble goniometer for GIRN, GERN, and GERP on both arms. TAM was calculated separately as the sum of internal and external rotational measurements under neutral and pronated conditions.

Results: Within pitchers and position players, all measurements were statistically reduced for the throwing arm ($P \leq 0.03$) except for GERN of the pitchers. GERP measures were significantly less than GERN for both arms of each group ($P < 0.01$): pitchers throwing arm +11.8°/nonthrowing arm +4.8°, position players throwing arm = +8.6°/nonthrowing arm +4.0°.

Conclusion: The forearm position of pronation, which appears to be mediated by tightness of the biceps, decreases GER capacity and TAM. GER and TAM should be calculated in neutral and pronated positions, considering that 80% of the players have a demonstrated difference between 8° and 12°.

Clinical Relevance: Measurement of GERP more accurately reflects the GER required in throwing, allows better quantification of the motion capacity necessary to withstand the loads in throwing, and may suggest interventions for at risk athletes.

Keywords: shoulder rotation; glenohumeral external rotation; total arc of motion

Alterations in the amount of glenohumeral range of motion have been commonly demonstrated in association with overhead throwing exposure in baseball players and other overhead throwing athletes.[25,28] Several studies have linked these alterations with increased injury risk in the shoulder and elbow of these athletes.[4,10,11,13,23,26,31,40,48-50] The alterations are thought to affect injury risk by creating changes in optimal glenohumeral and elbow kinematics affecting dynamic glenohumeral concavity/compression and stability and elbow position and loads.[2,14-17,30,35,36,38,42]

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Figure 1. Power position during throwing sequence demonstrating the pronated forearm position.

Studies have evaluated glenohumeral internal rotation (GIR), glenohumeral external rotation (GER), and the total arc of motion (TAM: sum of internal rotation [IR] plus external rotation [ER]), and alterations in all the individual motions have been associated with increased injury risk. Despite a consensus, it appears that the optimization of both GIR and GER in the physiologic ranges of motion are necessary to optimize throwing arm kinematics, so that TAM is optimized, and the shoulder and elbow can withstand the large motions and high loads and forces seen in throwing.[1,3,21,24,32,40,45,46]

The TAM concept has been demonstrated to have good clinical utility.[50] It describes the total available range of motion capability of the shoulder and provides an accurate measurement of the side-to-side differences that will occur. While most of the original attention was focused on GIR deficits, GER as an important variable in TAM has been studied more closely in recent studies. Wilk et al has determined that insufficient GER (<5°-8° throwing side to nonthrowing side differences) is associated with increased injury risk and has advocated this measurement as useful in identifying overhead athletes with increased risk of injury.[50] Decreased GER was also found to be a greater predictor of injury than GIR deficits.[6] In addition, a meta-analysis concluded that professional baseball players were at 2 times risk of injury if the throwing side to nonthrowing side difference in GER was not at least greater than 5° to 8°.[40] Because of these findings, more attention has been placed on evaluating and optimizing GER in injury risk modification programs.

Both GIR and GER have been measured with a high degree of reliability by goniometric methods.[27,28,43,48-50] For both motions, the arm is placed at 90° of abduction, on a hard surface, with a stabilized scapula, and is rotated to tightness. Every description of the measurement method also places the elbow at 90° of flexion, with the forearm in neutral. It was assumed that measurement of GER in this neutral forearm position (GERN) would accurately reflect the capacity of the athlete to achieve the necessary cocking motions in abduction ER for throwing. However, kinematic evaluations and observational experience demonstrates that the arm is not in a neutral forearm position in cocking, but that the throwing motion requires forearm pronation to achieve optimal cocking in the "power position" when the arm moves into horizontal abduction in cocking (Figure 1).[8,9,19,20,29] This position of pronation does have the potential to change the range of motion of the shoulder in ER because of possible increases in length and tension of the biceps. No previous studies have evaluated GER with the forearm in pronation in this key position.

Pilot studies at our institution demonstrated frequent differences between GERN and forearm pronated ER (GERP). GERP was a smaller value than GERN, indicating less ER capability and possibly less TAM capability in the throwing shoulder. The current study was developed to evaluate GERP, the amount of GERN-GERP difference, and the effect of GERP on TAM values. The hypotheses were (1) GERP would be less than GERN and (2) there would be a significant difference in total range of motion between neutral and pronated conditions with the pronated condition being less.

METHODS

Pitchers and position players from various Minor League Baseball affiliates within one Major League Baseball organization were assessed during spring training over a 2-year period (2017-2019). Inclusion criteria was as follows: any player regardless of position currently involved in spring training activities for the Kansas City Royals Baseball Organization and no current injury or condition limiting or restricting participation in baseball activities. Age, height, weight, throwing arm, position, and previous surgery were recorded. This study is a retrospective analysis of preexisting deidentified data. The retrospective study was reviewed by an institutional review board and received an approval for consent exemption because of the deidentified nature of the data (Approval No. 003809).

The measurements were taken at the same time of day and at the same time during spring training, before any baseball or conditioning activity in that day, to minimize the possibility of alteration of range of motion from those activities. GIR and GER motions were measured bilaterally with a standard bubble goniometer. Each subject was placed in a supine position on a flat level surface. A second examiner was positioned behind the player to properly stabilize the scapula during testing by applying a posteriorly directed force to the coracoid and scapula to ensure

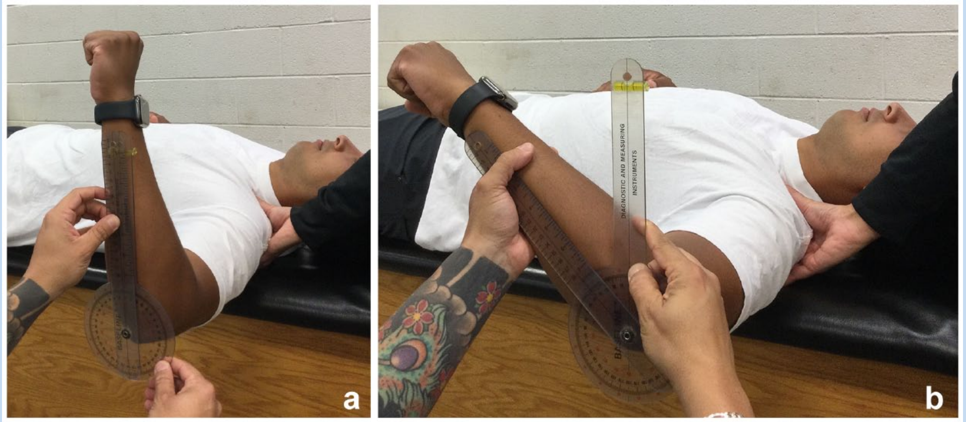

Figure 2. Glenohumeral internal rotation measurement beginning position (a) and terminal position (b).

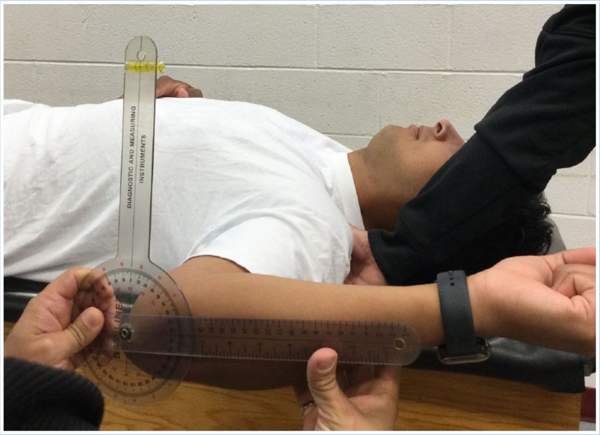

Figure 3. Terminal position of glenohumeral external rotation measurement with forearm in neutral position.

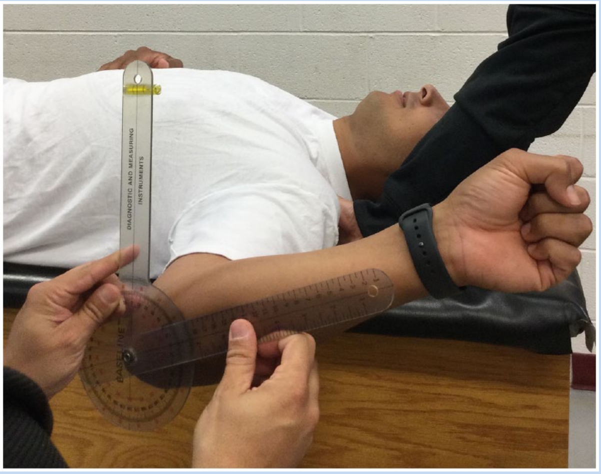

Figure 4. Terminal position of glenohumeral external rotation measurement with forearm in pronation.

that scapular movement did not occur.[27,51] This examiner also read and recorded the measurements obtained by the first examiner. The humerus was supported on the surface with the elbow placed at 90°, the arm on a bolster in the plane of the scapula, and the forearm in a position of neutral rotation. The following landmarks were identified before placing the goniometer: the fulcrum was set at the olecranon process of the elbow, the stationary arm perpendicular to the table as documented by the bubble on the goniometer, and the moving arm in line with the styloid process of the ulna. Each subject was then advised to relax, while the humerus was passively moved into internal rotation. Rotation was taken to "tightness," a point where no more glenohumeral motion would occur unless outside pressure was applied or the scapula would move (Figure 2a and b). The humerus was then moved into an externally rotated position to "tightness" (GERN) (Figure 3). The arm was not forced at the end of the motion, with no applied pressure, but was guided by the examiner and allowed to move to its end point. The measure was recorded once the humeral motion ceased. The arm was then returned to the starting position. The final measurement followed the same procedures except the forearm was placed in a full pronated position and held in this position before passively guiding and allowing the arm to move into the end point of ER (GERP) (Figure 4). The procedures were repeated bilaterally to obtain measurements from both the throwing and nonthrowing shoulder. Elbow pronation/supination range of motion measurements were not done in this study.

Data Analysis

In addition to obtaining GIR, GERN, and GERP, TAM was calculated by adding the GIR measurement to each of the GERN

Table 1. Reliability analysis for range of motion measurements

	ICC (95% CI)	SEM	MDC_{90}
Internal rotation: Throwing arm	0.96 (0.85, 0.99)	2.3	3.3
Internal rotation: Nonthrowing arm	0.70 (–0.10, 0.92)	3.7	3.1
External rotation neutral: Throwing arm	0.83 (0.33, 0.96)	2.2	2.5
External rotation neutral: Nonthrowing arm	0.94 (0.77, 0.99)	2.3	5.2
External rotation pronated: Throwing arm	0.94 (0.76, 0.98)	1.8	3.2
External rotation pronated: Nonthrowing arm	0.89 (0.56, 0.97)	2.2	3.1

ICC, intraclass correlation coefficient; MDC_{90}, minimal detectable change at the 90% confidence level; SEM, standard error of measurement.

and GERP measurements, resulting in neutral (TAMN) and pronated (TAMP) total motion values. The distribution of data for each variable was assessed for normality using the Shapiro-Wilk test. The variables were determined to be normally distributed. To examine GIR, GERN, GERP, TAMN, and TAMP motion for each arm between playing positions, independent *t* tests were employed. To examine side-to-side motion differences, separate 2 (throwing arm vs nonthrowing arm) × 2 (neutral vs pronated position) repeated-measures analysis of variance were performed for all subjects and each playing position. Mauchley's test was used to determine if the assumption of sphericity had been violated. In the event sphericity could not be assumed, a Greenhouse-Geisser correction was employed. Bonferroni post hoc analyses were employed to determine if differences existed between each measurement. Alpha was set at $P < 0.05$ for all comparisons. Based on pilot data where a mean difference of 10° occurred between GERN and GERP with a common SD of 8°, a total of 40 subjects would be needed for an 82% chance of correctly rejecting the null hypothesis that there would be no difference between the 2 types of ER measurements. All statistical calculations were performed using SPSS 26 (IBM, Armonk, NY).

To ensure the consistency of measurement obtained by the examiner, a reliability assessment for each motion was performed using the same 2 examiner procedures described earlier. A sample of 10 subjects not included in the actual study were obtained for this purpose. Using a 2-way random design (2, 1), intraclass correlation coefficients (ICC) were calculated from 2 trials of each position obtained (GIR, GERN, and GERP) for a single examiner. This same examiner also gathered all the study data for all trials. Intrasession test/retest reliability was calculated. Once the ICCs were determined, SE of measurement and minimal detectable change at the 90% confidence level were calculated. An ICC ≥0.75 was interpreted as excellent while values between 0.40 and 0.74 were considered fair to good and <0.40 was considered poor.[7]

RESULTS

Test/retest reliability was excellent for all test positions (ICC ≥ 0.80) except for IR of the nondominant arm, which was rated as good (ICC = 0.70) (Table 1). Demographic variables are summarized in Table 2. Sixty players (age 24.3 ± 1.8 years; height 186.5 ± 5.2 cm; weight 88.2 ± 9.9 kg) from a single professional baseball organization were examined for this study. The study sample included 32 pitchers and 28 position players (17 outfielders, 6 infielders, 4 catchers, and 1 utility player). A statistically significant difference existed for height with pitchers being 5 cm taller compared with position players ($P < 0.01$). Eighteen percent of all players (11 of 60) reported a previous surgery to the shoulder or elbow. There were significantly more pitchers who had previous surgery compared with position players (9 vs 2, $P = 0.04$).

Between the groups, pitchers had significantly less GIR (–7.3°, $P < 0.01$) and TAMP (–6.7°, $P = 0.02$) compared with position players in the throwing arm (Table 3). Within the groups, all measurements were statistically reduced for the throwing arm ($P \le 0.03$) except no difference occurred between arms for the GERN of the pitchers (Table 4). GERP measures were significantly less than GERN for both arms of each group ($P < 0.001$): pitchers throwing arm GERN-GERP = +11.8°/nonthrowing arm +4.8°, position players throwing arm GERN-GERP = +8.6°/nonthrowing arm +4.0°. Fifteen of 60 players (25%) had <5° side-to-side TAM difference, using the GERN values, compared with 9 of 60 players (15%) using the GERP values. 80% of players (48 of 60) had GERN-GERP values that exceeded SE of measurement while 20% (12 of 60) had values below the SE.

DISCUSSION

The hypotheses of the study were accepted. For the entire group, GERP was significantly less than GERN, and the resulting TAMP was significantly less than TAMN. These findings suggest that the pronated forearm position, in the setting of shoulder

Table 2. Demographic summary

	Overall (n = 60)	Pitchers (n = 32)	Position Players (n = 28)	P^a
Age, y				
Mean (SD)	24.3 (1.8)	24.1 (2.0)	24.4 (1.6)	0.64
Range	20-28	20-28	20-27	
Height, cm				
Mean (SD)	186.5 (5.2)	188.9 (4.5)	183.9 (4.8)	<0.01
Range	175-198	183-192	175-193	
Weight, kg				
Mean (SD)	88.2 (9.9)	90.0 (9.8)	86.3 (10.0)	0.24
Range	66-105	73-105	66-105	
Previous surgery, n (%)				
Yes	11 (18)	9 (28)	2 (7)	0.04
No	49 (82)	23 (72)	26 (93)	

[a]Comparison between pitchers and position players.

Table 3. Motion comparisons by position reported as mean (SD)

	Pitchers (n = 32)	Position Players (n = 28)	*P*
Internal rotation			
Throwing	24.8 (8.9)	32.1 (6.5)	<0.01
Nonthrowing	34.4 (9.2)	37.2 (7.0)	0.20
External rotation neutral			
Throwing	85.2 (9.5)	81.5 (9.2)	0.13
Nonthrowing	86.2 (10.4)	85.2 (5.5)	0.67
External rotation pronated			
Throwing	73.4 (10.0)	72.9 (9.0)	0.82
Nonthrowing	81.4 (9.5)	81.2 (5.7)	0.91
Total arc neutral			
Throwing	110.0 (10.5)	113.6 (11.8)	0.21
Nonthrowing	120.6 (9.6)	122.4 (9.1)	0.45
Total arc pronated			
Throwing	98.3 (10.7)	105.0 (10.4)	0.02
Nonthrowing	115.8 (9)	118.4 (10.1)	0.30

Table 4. Motion comparisons between measurement techniques reported as mean (SD)

	Throwing	Nonthrowing	*P*
Overall (n = 60)			
Internal rotation	28.2 (8.6)	35.7 (8.3)	<0.01
External rotation neutral	83.5 (9.5)[a]	85.7 (8.4)[a]	0.06
External rotation pronated	73.2 (9.5)	81.3 (7.9)	<0.01
Total arc neutral	111.7 (11.2)[a]	121.4 (9.4)[a]	<0.01
Total arc pronated	101.4 (11.0)	117.0 (9.5)	<0.01
Pitchers (n = 32)			
Internal rotation	24.8 (8.9)	34.4 (9.2)	<0.01
External rotation neutral	85.2 (9.5)[a]	86.2 (10.4)[a]	0.55
External rotation pronated	73.4 (10.0)	81.4 (9.5)	<0.01
Total arc neutral	110.0 (10.5)[a]	120.6 (9.6)[a]	<0.01
Total arc pronated	98.3 (10.7)	115.8 (9.0)	<0.01
Position players (n = 28)			
Internal rotation	32.1 (6.5)	37.2 (7.0)	<0.01
External rotation neutral	81.5 (9.2)[a]	85.2 (5.5)[a]	0.03
External rotation pronated	72.9 (9.0)	81.2 (5.7)	<0.01
Total arc neutral	113.6 (11.8)[a]	122.4 (9.1)[a]	<0.01
Total arc pronated	105.0 (10.4)	118.4 (10.1)	<0.01

[a]Neutral position significantly greater compared with pronated position ($P < 0.01$).

abduction in the scapular plane can alter GER capacity. These alterations could limit the increase in GER that has been suggested to be necessary for decreased injury risk and have effects on optimal glenohumeral and elbow kinematics and kinetics.

The kinematics of the throwing motion have been well described and point to the cocking position of abduction ER and ball release as key points at which maximum loads are encountered.[4,11,12,47,49] Optimum arm positions will minimize the loads and decrease the injury risk.[12,33,40,42] GER is becoming more recognized as an important component of optimal kinematics and is being shown to be associated with increased injury risk. GER is required to achieve the optimum hand position to facilitate full cocking and to move the arm in the most effective arc of motion to throw.

Decreased GER capacity can result in deleterious adaptations as the thrower tries to maintain maximum ball throwing function, or to achieve the optimum arm position. The thrower may not achieve the optimal cocking position but still throw, resulting in "short arming" the throw. Or the thrower will try to achieve a larger amount of horizontal abduction, which would place the hand in the desired position but increase the loads on the shoulder and elbow.[17,33] Excessive horizontal abduction out of the plane of the scapula[18,37] and excessive GER[17,50] have been shown to produce increased loads and injury risks. Therefore, measuring GERP is clinically necessary to more accurately identify possible tightness that could translate to increased loads on the shoulder during throwing. GERP most accurately estimates the actual capacity to achieve the appropriate arm position because of the requirement of forearm pronation. Eighty percent of the players (48 of 60) demonstrated a significant amount of deficit, with GERP being less than GERN. However, considering that the measurements in 12 of the 60 players (20%) were not beyond SE of measurement between GERN and GERP, measurement of GERN should not be abandoned.

Decreased GER capacity also resulted in decreased TAM capacity, so that TAMP is less than TAMN. The TAM concept suggests that the dominant arm TAM should be equal to or within 5° to 8° more than the nonthrowing arm, owing to concerns about the increased motion creating increased loads.[50] The decreases in GERP may fail to identify the players that may benefit from interventions to improve the effective range of motion capacity. Therefore, it may be beneficial to include the GERP measurement as well as the GERN measurement when determining TAM.

The mechanism by which the pronated forearm position can alter GER is probably based on altered biceps length, tension, and stiffness. The position of forearm pronation results in maximal length of the biceps from origin to insertion, thus increasing the internal tension of the biceps, and will not allow optimal lengthening of the muscle from origin to insertion, resulting in decreased capacity for GER when the forearm is pronated. The biceps has been demonstrated to exhibit a high amount of change in length and stiffness after repetitive eccentric loads.[22,44] The mechanism of the increased biceps tension could be considered another example of soft tissue adaptation to repetitive high levels of tensile loads, with resulting stiffness and volume changes that has been demonstrated in other muscles.[5,26-28,34,39,41]

In addition to altering GER and TAM, increased biceps tension can affect the strain and distribution of the loads on the labrum. Evaluations that would identify possible increases in the inherent biceps tension, such as including measurements of GERP, could be beneficial to try to minimize the deleterious effects of the increased tension on the joint structures.

This study included measurements from both pitchers and position players to identify any differences between athletes that might be due to the known differences in the amount of throwing. The statistically significant differences between the 2 groups seen in TAMP were mainly because of the statistically significant differences in GIR, as the GERN-GERP values were not statistically different. This indicates that the throwing motion itself produces the loads that create the differences in GER, and that both pitchers and position players should be evaluated for these changes.

Limitations

There are several limitations to this study. Elbow pronation/supination range of motion measurements were not obtained, so the exact amount of forearm motion is not known. This traditional method of measurement is obtained in an arm position that has no clinical correlation with the arm position, forearm position, or biceps length that would be required in throwing, so it was not deemed important in this study to assess this measurement.

All the measurements were taken at one point in the baseball season, and at one point in the training program. All the current recommendations from other studies about injury risk and indications are based on this method of data collection. However, other studies have shown that glenohumeral range of motion measurements may vary depending on the time since last throwing exposure, and that there is probably a curve of response that may more accurately depict the actual adaptations and give a better insight into the kinematic alterations.[27,43] Future studies could be designed to assess the possible change in these variables over the course of the season.

The GIR, GER, and TAM values reported in this study are less than values reported in other studies.[50] This probably reflects slight differences in the exact technique of the measurement. In this study, the arm motion was completely passive, in that the arm was guided by the examiner to the position of tightness, but no pressure was placed on the arm. Other testing procedures have been described as applying some over pressure to assure the full range of motion capacity was reached. This could introduce some increase in the measurement because of the stretching of the tissues.

There was no independent evaluation of the amount of biceps tightness or of the possible biomechanical or physiological reasons for the tightness. However, this type of response would be characteristic in a muscle that is placed in repetitive positions of high tensile load and has been demonstrated in biceps muscles subjected to repetitive eccentric loads. Future studies should evaluate for possible changes in biceps structure and response to tensile load.

Finally, this study was only a descriptive study, confirming an on the field clinical observation and demonstrating the characteristics of the difference in motion between the 2 experimental conditions. The results have not been validated regarding providing recommendations about using the range of motion in pronation measurements as part of recommendations about injury risk. This information will need to be obtained through a prospective study that looks at both sets of GER measurements and evaluates injury incidence and the resulting risk.

CONCLUSION

GER capacity is becoming more frequently identified with increased injury risk. Forearm position does affect GER capacity so that the pronated position of the forearm could decrease GER capacity in the important arm position of cocking. This alteration appears to be mediated by tightness of the biceps because of the forearm pronation. Since pronation is occurring throughout the motion into cocking, this method of evaluation of GER capacity may clarify the dynamics of the motion. GERN is not a good single estimation of the capability to achieve the important position of cocking. Considering 80% of the players had a demonstrated decrease of GER with the pronated forearm, GER should be measured with the forearm both in neutral and pronation and TAM should be calculated in the same forearm positions.

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