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Glenohumeral rotation deficits in high school, college, and professional baseball pitchers with and without a medial ulnar collateral ligament injury

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Background: It is unclear how a glenohumeral internal rotation (IR) loss (GIRLoss), a glenohumeral external rotation (ER) gain (GERGain), or a total rotational motion (TRM) deficit (TRMD) predict medial ulnar collateral ligament (MUCL) injury risk among high school (HS), college (COLL), and professional (PRO) baseball pitchers with and without MUCL injury. We hypothesized that pitchers with MUCL injury would have more GIRLoss and TRMD compared with pitchers without MUCL injury, with no differences in IR, ER, TRM, GIRLoss, GERGain, and TRMD.

Methods: The study equally divided 216 male HS, COLL, and PRO pitchers into the MUCL injury group (n = 108) and a control group (n = 108) without MUCL injury. The control group was matched with the MUCL injury group according to number, level of play, and age. Bilateral shoulder passive IR/ER was measured and GIRLoss, GERGain, TRM, and TRMD calculated. A 2-way analysis of variance ($P < .05$) was used to assess shoulder rotational differences among the 2 groups and 3 pitching levels.

Results: Compared with the control group, the MUCL injured group had more GIRLoss (21° ± 14° vs. 13° ± 8°; $P < .001$), GERGain (14° ± 9° vs. 10° ± 9°; $P = .004$), and TRMD (7° ± 13° vs. 3° ± 9°; $P = .008$). For all pitching levels, approximately 60% of pitchers in MUCL injury group had GIRLoss >18° compared with approximately 30% of those in the control group. Approximately 60% of pitchers in the MUCL injury group had TRMD >5° compared with 50% of pitchers in the control group. No differences were observed among HS, COLL, and PRO pitchers for GIRLoss (16° ± 12°, 17° ± 11°, 19° ± 13°, respectively; $P = .131$), GERGain (11° ± 9°, 11° ± 10°, 13° ± 10°, respectively; $P = .171$), TRMD (5° ± 11°, 6° ± 11°, 5° ± 14°, respectively; $P = .711$), and throwing shoulder ER (111° ± 10°, 111° ± 11°, 113° ± 9°, respectively; $P = .427$), IR (50° ± 11°, 49° ± 11°, 48° ± 10°, respectively; $P = .121$), and TRM (162° ± 14°, 160° ± 15°, 161° ± 14°, respectively; $P = .770$).

The Baptist Hospital (Gulf Breeze, FL, USA) Institutional Review Board approved this study (#419657-1).

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Conclusions: Greater GIRLoss, GERGain, and TRMD in MUCL injured pitchers compared with uninjured pitchers implies these variables may be related to increased MUCL injury risk, especially because GIRLoss >18° and TRMD >5° demonstrate an increased MUCL injury risk. Shoulder rotational motion and deficits do not vary among HS, COLL, and PRO levels of pitchers.
Level of evidence: Level II; Retrospective Design; Prognosis Study

Keywords: Baseball; MUCL; GIRLoss; pitchers; shoulder; elbow

In healthy baseball pitchers, Wilk et al, [24] Reinold et al, [20] and Borsa et al[3] stated that the total rotational motion (TRM) at the shoulder, which is the sum of shoulder internal rotation (IR) and external rotation (ER), was approximately the same in both the throwing and nonthrowing shoulders. They went on to state that the normal throwing shoulder presented with approximately 5° to 12° more ER and approximately 11° to 13° less IR compared with the nonthrowing shoulder. However, several studies have shown that pitchers may be at an increased risk of shoulder or elbow injury when they had a glenohumeral IR loss (GIRLoss) of approximately 15° to 25° in their throwing shoulder compared with their nonthrowing shoulder or when they had a TRM deficit (TRMD) of >5° between their throwing and nonthrowing shoulders.[8,11,19,22,26,27]

Because GIRLoss in the literature has been defined differently among clinicians, with a large range of between approximately 13° and 25°, a panel of throwing shoulder experts (researchers and clinicians with extensive peer reviewed shoulder publications and clinical experience) were assembled and developed a consensus statement that defined GIRLoss as >18° and defined TRMD as >5° in terms of being predictive of shoulder or elbow injuries.[15]

We know of only 2 studies that have measured the effects of GIRLoss and TRMD in baseball players with ulnar collateral ligament (MUCL) injuries, and both studies combined pitchers, catchers, infielders, and outfielders.[8,11] We know of no studies that have investigated GIRLoss, TRMD, and a glenohumeral ER excess (GERGain, defined as excess in ER in throwing arm relative to the nonthrowing arm) in baseball pitchers exclusively in relation to MUCL injuries, and how much GERGain is excessive enough to increase MUCL injury risk is unknown. However, Wilk et al[26] did report that there was no correlation between elbow injuries and an ER insufficiency in professional (PRO) pitchers, which they defined as when the ER of the throwing shoulder was not at least 5° more than the ER of the nonthrowing shoulder.

There are also no known studies that have investigated the effects of GIRLoss, GERGain, and TRMD in relation to MUCL injury among different pitching levels, such as high school (HS), college (COLL), and PRO pitchers. Therefore, the primary purpose of this study was to determine whether GIRLoss, GERGain, and TRMD were significantly different between pitchers with and without a MUCL injury and significantly different among HS, COLL, and PRO pitching levels. A secondary purpose was to determine whether throwing arm IR, ER, and TRM was significantly different among HS, COLL, and PRO pitching levels. We hypothesized that baseball pitchers who had a MUCL injury would have significantly greater GIRLoss and TRMD compared with pitchers who did not have a MUCL injury. A further hypothesis was that there would be no significant differences in GIRLoss, GERGain, and TRMD, or in throwing arm IR, ER, and TRM among HS, COLL, and PRO pitching levels.

Materials and methods

Participants

The study equally divided 216 male HS, COLL, and PRO baseball pitchers into an MUCL injury group (n = 108) and a control group without an MUCL injury (n = 108). The healthy control group was matched with the MUCL injury group according to the number of participants in the group, their pitching level, and their age. The MUCL injury group and the control group each contained 45 HS pitchers (range, 15-18 years; 16.8 ± 1.1 years), 45 COLL pitchers (range, 19-22 years; 20.4 ± 1.2 years), and 18 PRO pitchers (range, 19-32 years; 24.8 ± 4.4 years). Approximately 80% of the players in both groups were right-handed pitchers and 20% were left-handed pitchers.

Inclusion criteria for the MUCL injury group consisted of all players diagnosed with an acute MUCL tear that adversely affected their ability to pitch secondary to pain along the medial aspect of their elbow, clinical examination findings consistent with an MUCL tear and MUCL insufficiency, magnetic resonance imaging (MRI) findings consistent with an MUCL tear, and all players who subsequently underwent UCL reconstruction after all glenohumeral IR and ER passive range of motion (PROM) measurement data were collected. An experienced senior orthopedic surgeon performed the clinical examination, and the MRI scans were read by a board-certified radiologist. Inclusion criteria for the control group consisted of currently playing baseball and pitching.

Exclusion criteria for the MUCL injury group and the control group consisted of any previous shoulder or elbow surgery, any previous shoulder or elbow injuries that prevented them from pitching over the past 12 months, if they played additional positions other than pitcher, and if they were retired from baseball. All participants provided written informed consent.

Procedures

Bilateral shoulder IR and ER PROM were measured in the MUCL injured group by 2 experienced testers, with each tester having more than 10 years' experience in measuring IR and ER in baseball pitchers. One tester (senior orthopedic surgeon) passively rotated the shoulder in IR and ER, and the other tester (senior physical therapist) aligned the goniometer and read and recorded the measurement. The same 2 experienced testers performed the same IR and ER measurements in the control group, with the senior physical therapist being blinded to the 2 testing groups. The measurement technique used has been previously described[8,11,20,22,24,27,28] and has generally been shown to have good to excellent reliability.[11,20,22,24,27]

Participants were positioned supine with the shoulder at 90° of abduction, approximately 10° of horizontal adduction (scapular plane), and with 90° of elbow flexion. The tester stabilized the scapula by grasping the coracoid process and the spine of the scapula posteriorly and then rotated the shoulder internally or externally until end range, defined as the instant the participant's scapula moved under the stabilizing hand. For the IR and ER measurements, the fulcrum of a standard goniometer was positioned over the olecranon process, the bubble inclinometer helped ensure perpendicular alignment of the stationary arm of the goniometer relative to the ground, and the moveable arm aligned along the ulna to the ulnar styloid process. The tester then recorded IR or ER measurements. GIRLoss, GERGain, and TRMD were calculated for all participants as follows:

GIRLoss = (nonthrowing shoulder IR PROM)
– (throwing shoulder IR PROM)

GERGain = (throwing shoulder ER PROM)
– (nonthrowing shoulder ER PROM)

TRMD = (nonthrowing shoulder TRM)
– (throwing shoulder TRM)

Statistical analyses

A 2-way analysis of variance ($P < .05$) was used to assess the shoulder rotational measurements, and the 2 independent variables were group (with and without MUCL injury) and pitching level (HS, COLL, and PRO). If the analysis of variance revealed a significant difference, post hoc analyses were performed using Bonferroni *t* tests to evaluate the significance of between pairwise comparisons. The significance level was set at $P < .05$.

Results

Mean ± standard deviation values for GIRLoss, GERGain, and TRMD among the 3 pitching levels (HS, COLL, PRO) and the 2 groups (with and without MUCL injury) are reported below and in Table I. Compared with the control group, the MUCL injured group had a significantly greater GIRLoss (21° ± 14° vs. 13° ± 8°, $P < .001$), a significantly greater GERGain (14° ± 9° vs. 10° ± 9°, $P = .004$), and a significantly greater TRMD (7° ± 13° vs. 3° ± 9°, $P = .008$).

No significant differences were observed among the HS, COLL, and PRO pitching levels for GIRLoss (16° ± 12°, 17° ± 11°, and 19° ± 13°, respectively; $P = .131$), GERGain (11° ± 9°, 11° ± 10°, and 13° ± 10°, respectively; $P = .171$), and TRMD (5° ± 11°, 6° ± 11°, and 5° ± 14°, respectively; $P = .711$).

Differences were not significant for throwing shoulder ER (111° ± 10°, 111° ± 11°, and 113° ± 9°, respectively; $P = .427$), IR (50° ± 11°, 49° ± 11°, and 48° ± 10°, respectively; $P = .121$), and TRM (162° ± 14°, 160° ± 15°, 161° ± 14°, respectively; $P = .770$); or for nonthrowing shoulder ER ($P = .877$; 100° ± 10°, 100° ± 9°, and 100° ± 11°, respectively), IR ($P = .791$; 66° ± 10°, 67° ± 0°, and 66° ± 11°, respectively), and TRM ($P = .824$; 166° ± 14°, 167° ± 14°, 166° ± 13°, respectively).

The number and percentage of HS, COLL and PRO pitchers with GIRLoss and TRMD in the MUCL injured group and the control group are reported in Table II. A GIRLoss in excess of 18° was found in 56% of the pitchers in the MUCL injury group compared with 28% of those in the control group, and this was consistent among all 3 pitching levels. A TRMD in excess of 5° was found in 58% of the pitchers in the MUCL injury group compared with 50% of the those in the control group.

Table I GIRLoss, GERGain, and TRMD among pitching levels and groups with and without MUCL injury

Variable	Baseball pitchers with MUCL injury				Baseball pitchers without MUCL injury			
	HS	COLL	PRO	All	HS	COLL	PRO	All
	(n = 45)	(n = 45)	(n = 18)	(n = 108)	(n = 45)	(n = 45)	(n = 18)	(n = 108)
GIRLoss, °*	19 ± 14	21 ± 12	23 ± 15	21 ± 14	12 ± 8	12 ± 8	15 ± 9	13 ± 8
GERGain, ° †	13 ± 9	14° ± 10	14 ± 9	14 ± 9	8 ± 7	8 ± 9	14 ± 11	10 ± 9
TRMD, °‡	6 ± 12	7° ± 13°	9 ± 16	7 ± 13	4 ± 9	4 ± 8	1 ± 9	3 ± 9

GIRLoss, glenohumeral internal rotation loss; *GERGain,* glenohumeral external rotation gain; *TRMD*, total rotational motion deficit; *MUCL*, medial ulnar collateral ligament; *HS*, high school; *COLL*, college; *PRO*, professional; *IR*, internal rotation; *PROM*, passive range of motion; *ER*, external rotation; *TRM*, total rotational motion (shoulder ER PROM + shoulder IR PROM).

* GIRLoss = (nonthrowing shoulder IR PROM) – (throwing shoulder IR PROM). This was significantly different ($P < .001$) between all pitchers with and without MUCL injury.

† GERGain = (throwing shoulder ER PROM) – (nonthrowing shoulder ER PROM). This was significantly different ($P = .004$) between all pitchers with and without MUCL injury.

‡ TRMD = (nonthrowing shoulder TRM) – (throwing shoulder TRM). This was significantly different ($P = .008$) between all pitchers with and without MUCL injury.

Table II Number and percent of pitchers with GIRLoss and TRMD among pitching levels and groups with and without MUCL injury

Variables	Baseball pitchers with MUCL injury				Baseball pitchers without MUCL injury			
	HS	COLL	PRO	All	HS	COLL	PRO	All
	(n = 45)	(n = 45)	(n = 18)	(n = 108)	(n = 45)	(n = 45)	(n = 18)	(n = 108)
Pitchers with								
GIRLoss (>18°)								
No.	23	25	13	61	11	12	7	30
Percent	51	56	72	56	24	27	39	28
TRMD (>5°)								
No.	25	27	11	63	25	22	8	55
Percent	56	60	61	58	56	49	44	51

GIRLoss, glenohumeral internal rotation loss; *TRMD*, total rotational motion deficit; *MUCL*, medial ulnar collateral ligament; *HS*, high school; *COLL*, college; *PRO*, professional; *PROM*, passive range of motion; *IR*, internal rotation; *ER*, external rotation; *TRM*, total rotational motion (shoulder ER PROM + shoulder IR PROM).
GIRLoss = (nonthrowing shoulder IR PROM) − (throwing shoulder IR PROM).
TRMD = (nonthrowing shoulder TRM) − (throwing shoulder TRM).

Discussion

The current study is the only known study that has examined the relationship between shoulder rotational differences (GIRLoss, GERGain, TRMD) and MUCL injury in baseball pitchers diagnosed with a MUCL tear, given that 20% to 30% of the participants in the remaining 2 studies in the literature that also examined GIRLoss, TRMD, and MUCL injuries were position players (infielders, outfielders, or catchers) in addition to pitchers. Throwing volume and intensity is much different between position players and pitchers and could affect GIRLoss, GERGain, and TRMD when pitchers and position players are mixed and not considered separately. The current study is also the only known study that has assessed GERGain in relation to MUCL injuries and the only study that has assessed GIRLoss, GERGain, and TRMD among different levels of pitchers (HS vs. COLL, HS vs. PRO, COLL vs. PRO).

As hypothesized, GIRLoss and TRMD were significantly greater in the MUCL injury group compared with the control group. Garrison et al[11] also measured GIRLoss and TRMD in COLL and HS baseball players with and without MUCL injury. However, the current study only included pitchers, whereas Garrison et al[11] reported that 30% of their participants were nonpitchers (catchers, infielders, or outfielders). These position players do not throw a ball as hard or as often as pitchers do, which could affect GIRLoss over time. Nevertheless, similar to the current study, these authors reported the same TRMD in the MUCL group (7°), and as in the current study, they also reported TRMD was significantly greater in the MUCL injury group than in the control group. Based on their results, these authors concluded that the TRMD of 7° was associated with an MUCL tear in baseball players.

Moreover, Garrison et al[11] reported the same GIRLoss in the control group as in the current study (13°), but in contrast, they only found a 13° GIRLoss in the MUCL injury group. In the current study, a 21° GIRLoss occurred in the MUCL injury group, which was significantly greater than the 13° GIRLoss that occurred in the control group. This discrepancy in GIRLoss between Garrison et al[11] and the current study may have been partly because all players in the current study were pitchers, whereas 30% of the players were nonpitchers in the Garrison et al[11] study. It should also be emphasized that although significant differences were found in the current study, relatively large standard deviations were observed, which implies relatively large intersubject variability. Therefore, the clinical significance from these results is not clear for all measurements.

Dines et al[8] also measured GIRLoss in baseball players (HS, COLL, and PRO) with and without MUCL injury. Similar to Garrison et al,[11] Dines et al[8] also used catchers, infielders, and outfielders in addition to pitchers, but they included a higher percentage of pitchers than Garrison et al. Similar to the current study, Dines et al[8] reported that GIRLoss was significantly greater in the MUCL injury group than in the control group. The similar findings between the current study and Dines et al[8] compared with Garrison et al[11] may have occurred partly because compared with the current study, in which 100% of the participants were pitchers, the population for Dines et al had a higher percentage of pitchers compared with the population for Garrison et al.

Two additional studies assessed GIRLoss and TRMD in baseball players in relation to elbow injuries in general and not specifically to MUCL injuries.[22,26] Wilk et al[26] reported that although GIRLoss did not correlate with elbow injuries in PRO pitchers, those with a TRMD >5° had a 2.6-times greater risk for elbow injury than those with a TRMD ≤5°. We note that of the 49 players that comprised the elbow injury group from Wilk et al,[26] only 3 (6%) went on to have MUCL reconstruction, whereas in the current study, 100% of the players with an MUCL injury underwent MUCL reconstruction. However, caution should be noted, given the Wilk et al[26] study examined glenohumeral motion and monitored players for a future elbow injury, whereas the current study identified an MUCL injury and then subsequently examined glenohumeral motion.

Lee et al[17] examined the relationship between humeral retrotorsion and shoulder ROM in baseball players (pitchers, outfielders, infielders, and catchers) with an MUCL tear. These authors reported that in baseball players with an MUCL tear, approximately 16% of the variance in GIRLoss and 24% of the variance in ER ROM difference were attributed to differences found in humeral retrotorsion between sides. They reported that the results indicated that humeral retroversion contributed significantly to GIRLoss and increased ER ROM in baseball players. Because 25% of the sample were nonpitchers, whether these same results would occur in a group of all pitchers is unknown.

Shanley et al[22] assessed whether the incidence of shoulder and elbow injuries was increased in HS softball and baseball players who had GIRLoss. Although pitchers comprised only 21% of their participant pool, the pitchers sustained 44% of the total upper extremity injuries. In contrast to the current study, in which all of the pitchers had to have MUCL reconstruction, most of the elbow injuries were only minor. These authors reported that injured baseball pitchers who had a GIRLoss of >25° had a 10-times greater risk of upper extremity injuries compared with those who had a GIRLoss of <25°. However, how these upper extremity injuries are specifically related to MUCL injuries is unknown, because no MUCL injuries were reported in their study.

From more than 20 studies in the baseball pitching literature[1-9,11,16,19-26-29] that quantified ER, IR, and TRM between dominant and nondominant shoulders in healthy baseball pitchers with no history of shoulder or elbow pathology, large variabilities in ROM were reported across studies for ER, IR, and TRM secondary to patient variability and varying measurement techniques used,[28] such as using scapular stabilization, humeral head stabilization, or no stabilization. The ER ROM reported in the literature for healthy baseball pitchers was approximately 95° to 135° in the dominant shoulder (mean of approximately 125°) and 90° to 130° in the nondominant shoulder (mean of approximately 115°). The GERGain ROM reported in the literature for healthy baseball pitchers was approximately 5° to 15°, with a mean of approximately 9°, which is similar to the 10° mean reported in our healthy control group but in contrast to the 14° mean reported for our MUCL injury group.

The IR ROM reported in the literature for healthy baseball pitchers was approximately 20° to 80° in the dominant shoulder (mean of approximately 53°) and 35° to 90° in the nondominant shoulder (mean of approximately 64°). The GIRLoss ROM reported in the literature for healthy baseball pitchers was approximately 7° to 16°, with a mean of approximately 11°, which is similar to the 13° mean reported in our healthy control group but in contrast to the 21° mean reported for the MUCL injury group.

The TRM reported in the literature for healthy baseball pitchers was approximately 140° to 200° for both the dominant and nondominant shoulders (mean of approximately 180° for both shoulders). The mean TRMD of approximately 2° (which implies TRM is approximately 2° greater in the nondominant shoulder compared with the dominant shoulder, which is the same pattern observed in the current study) in the literature for healthy baseball pitchers is similar to the 3° mean reported in our healthy control group but in contrast to the 7° mean reported for the MUCL injury group.

As hypothesized, GIRLoss, GERGain, and TRMD were not significantly different among HS, COLL, and PRO pitching levels, although the PRO group was the only group that met the criteria for GIRLoss (>18°). This GIRLoss trend for the PRO group may suggest a potentially higher elbow injury risk compared with HS and COLL groups; however, this is only a trend, and this conclusion cannot be made given no significant differences were found among HS, COLL, and PRO groups. This is the first known study that has compared these measurements among different levels of pitchers. Therefore, given the scarcity of data in the literature that have compared GIRLoss, GERGain, and TRMD in HS, COLL, and PRO pitchers, more research is needed before definite conclusions can be made. Our current findings suggest that GIRLoss, GERGain, and TRMD measurements are similar among HS, COLL, and PRO pitchers.

This is the first known study that has reported GERGain in baseball pitchers in relation to elbow injury. The significantly greater GERGain in the MUCL injury group compared with the control group suggests that this measurement should be examined more closely in follow-up research studies. It is not possible to make any definite GERGain conclusions based on this initial finding, but this may be the beginning of a trend that may suggest that GERGain may be predictive of MUCL injuries. However, how much excessive ER in the throwing shoulder compared with the nonthrowing shoulder may contribute to MUCL injury risk is unknown.

In contrast to GERGain, Wilk et al[25,26] examined an ER insufficiency in the throwing arm and defined this as a pitcher having less than 5° more ER in throwing arm than nonthrowing arm. Although these authors reported that pitchers with an ER insufficiency were 2.2-times more likely to be placed on the disabled list for a shoulder injury,[25] they also reported that they found no correlation of ER insufficiency to elbow injury.[26] Therefore, having too little ER in the throwing shoulder compared with the nonthrowing shoulder may be less predictive of elbow injury risk compared with having too much ER in the throwing shoulder compared with the nonthrowing shoulder, as are the findings in the current study.

Although Garrison et al[11] also measured glenohumeral ER between throwing and nonthrowing shoulders in control and MUCL injury groups, they did not perform statistical comparisons, did not calculate, or did not discuss an insufficiency or excess in ER in the throwing arm compared with the nonthrowing arm, so no GERGain conclusions can be made from their data. Therefore, evidence in the literature is still insufficient to make any conclusive statements regarding GERGain in relation to MUCL injuries.

One limitation in the current study is that making conclusive statements that GIRLoss, GERGain, or TRMD cause MUCL injuries in baseball pitchers is difficult given the scarcity of data from the literature related to this issue. Moreover, which of these shoulder rotational deficit variables—GIRLoss, GERGain, or TRMD—is most related to MUCL injuries is also unknown. More research is needed before definitive conclusions can be made. However, the findings from the current study and the studies in the literature that related shoulder rotational differences to MUCL injuries[8,11] or elbow injuries[22,26] suggest that a GIRLoss >18° and a TRMD >5° may be associated with MUCL injury. Additional studies are needed to confirm and strengthen this premise.

There is also a limitation in the current study and in the literature that commonly uses GIRLoss to imply a deficit in IR when actually it is really a difference in IR because the humeral torsion (humeral retroversion) difference is not known and not used to actually calculate a true GIRLoss. The problem is that humeral retroversion is most accurately measured with diagnostic tools such as computed tomography and MRI, and these diagnostic tools are often not easily assessable and feasible for many clinicians who make these measurements, such as in PRO baseball pitchers during spring training in which time is a major factor. Nevertheless, future studies should be conducted to validate measurement variations in baseball pitchers between glenohumeral IR differences where humeral retroversion was not measured and true glenohumeral IR deficits where humeral retroversion was measured. Future studies should also examine whether the age (acute or chronic), extent (tear vs. complete rupture), and location (anterior, posterior, transverse ligament) of a MUCL injury plays a role in GIRLoss, GERGain, or TRMD measurements.

Another limitation in the current study is the inherent variability issues when measuring IR and ER with goniometers. These measurements have been demonstrated to vary according to the population studied (eg, baseball pitchers vs. nonpitchers), the motion measured (eg, IR vs. ER), and the technique used (eg, moving the shoulder or elbow to tissue resistance vs. beyond tissue resistance; stabilizing vs. not stabilizing scapula or humeral head), differentiating movement of the coracoid from rolling muscle bands in throwers with thick shoulder musculature, malposition of the scapula, and if intrarater or inter-rater measurements were used, with intrarater being more accurate and less variable than inter-rater.[1-7,9,10,12-14,16,18-24,26,28,29] In the literature, the reliability for the same method used for baseball players as in the current study has generally been reported to be good to excellent.[11,14,19,20,22,24,27] Although Wilk et al[28] reported only fair intrarater intraclass correlation coefficient (ICC) values between 0.48 and 0.68 for IR and ER, Myers et al[19] reported intrarater ICC values for ER and IR between 0.85 and 0.94 and standard error of the mean values of approximately 3°. Moreover, Hurd et al[14] reported intrarater ICC values between 0.94 and 0.99, Garrison et al[11] reported an intrarater ICC value of 0.97 for both ER and IR, Shanley et al[22] reported intrarater ICC values of 0.99 for ER and 0.97 for IR, and Reinold et al[20] and Wilk et al[24,27] reported intrarater ICC values of 0.87 for ER and 0.81 for IR. IR and ER measurement error and variability were therefore minimized in the current study because the same measurement technique involving scapular stabilization was used in this study, similar to the aforementioned studies in the literature that generally reported good to excellent intrarater reliability, and because the same experienced testers were used for both the MUCL injury group and the control group.

Conclusion

The greater GIRLoss, GERGain, and TRMD in pitchers with an MUCL injury compared with pitchers without a MUCL injury implies that these variables may be important to monitor in pitchers because they may be related to an increased MUCL injury risk, especially because a GIRLoss >18° and a TRMD >5° have been previously demonstrated to be predictive of elbow injuries, including MUCL injuries. The findings from the current study will assist clinicians to better understand how GIRLoss, GERGain, and TRMD can be predictors of MUCL injuries. Shoulder rotational motion and deficits do not vary significantly among HS, COLL, and PRO levels of pitchers.

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