Available online at www.sciencedirect.com
ScienceDirect
www.jsesinternational.org

Humeral retrotorsion corrected glenohumeral external rotation deficits are present in medial ulnar collateral ligament injured and uninjured college baseball players

Jacob E. Vasquez, PT, DPT, OCS[a], Frankie-Ann McCauley, PT, DPT, SCS, CSCS[a], Claire M. Reynolds, PT, DPT, SCS[a], Sean M. Kennedy, PT, DPT, PhD, SCS, CSCS[b], Jacob D. Jelmini, PhD, ATC, CSCS[a], Zachary A. Gehring[c], J. Craig Garrison, PT, PhD, SCS, ATC[a], John E. Conway, MD[c], and Natalie L. Myers, PhD, ATC, PES[d,*]

[a]Memorial Hermann Health, Rockets Sports Medicine Institute, Houston, TX, USA
[b]AdventHealth Sports Med and Rehab, Orlando, FL, USA
[c]University of Texas Health Sciences Center, McGovern School of Medicine, Houston, TX, USA
[d]ATI Physical Therapy, Institute for Musculoskeletal Advancement, Downers Grove, IL, USA

ARTICLE INFO

Keywords:
Baseball
Shoulder
Humeral retrotorsion
Rotational motion
Deficit
Retrotorsion corrected motion

ABSTRACT

Background: Glenohumeral rotational motion should be interpreted within the context of relative humeral retrotorsion (rHRT). To date, no study has investigated shoulder rotational motion within the context of rHRT in a medial ulnar collateral ligament (MUCL)–injured population. Therefore, the purpose of this study was to determine if there were differences in HRT-corrected rotational motion between MUCL-injured and uninjured college baseball players.

Methods: Thirty-five baseball players diagnosed with an MUCL injury were matched with 35 uninjured controls. Glenohumeral external rotation (GER) and internal rotation (GIR), as well as anatomic HRT, were collected on both arms. Data reduction was performed for all objective

All injured participants read and signed an electronic informed consent form approved by The University of Texas Health Science Center at Houston (IRB approval #:HSC-MH-21-1041) prior to enrollment in the study. All uninjured participants read and signed an electronic informed consent form approved by The University of Texas Health Science Center at Houston (IRB approval #:HSC-MH-22-0537) prior to enrollment in the study.

*Corresponding author: Natalie L. Myers, PhD, ATC, PES, ATI Physical Therapy, Institute for Musculoskeletal Advancement, 2001 Butterfield Rd, Suite 1600, Downers Grove, IL 60515, USA.
E-mail address: nmyers02@gmail.com (N.L. Myers).

https://doi.org/10.1016/j.jseint.2025.10.001
2666-6383/

rotational motions and anatomic HRT, which was used to quantify rHRT. rHRT was then used to calculate HRT-corrected GER and HRT-corrected GIR. Outcomes were compared between groups using multivariate analysis of covariance, controlling for baseline cohort differences.
Results: Results indicated no significant multivariate effects of cohort, body mass index, or level of competition on HRT-corrected GER or GIR (all Pillai's Trace $P > .05$, partial $\eta^2 \leq 0.019$). Adjusted estimated marginal means for HRT-corrected GER were $-9.99°$ (standard error [SE] = 2.51) for the MUCL cohort and $-5.45°$ (SE = 2.51) for the uninjured cohort; for HRT-corrected GIR, they were 5.01° (SE = 2.46) and 2.21° (SE = 2.46), respectively.
Conclusion: HRT-corrected GER deficits are more prevalent than HRT-corrected GIR deficits in both cohorts. These findings continue to highlight the importance of accounting for osseous adaptations in range of motion measurements, as GIR deficit is not as common as previously thought.
Level of evidence: Level III; Retrospective Case Control Comparison; Prognosis Study

Elbow pathology is prevalent in the baseball athlete.[49] Researchers have consistently found that the medial elbow is most commonly injured across different levels of play, with injuries to the medial ulnar collateral ligament (MUCL) being the primary source of athletic disability.[7,41,43] The extreme valgus forces that occur at the medial elbow during the late cocking phase of throwing predisposes baseball players to medial-sided instability and MUCL pathology.[16] This injury has specifically impacted the collegiate athlete,[41] with MUCL reconstruction rising as much as 193% in the past 20 years, with significant increases in players aged 17-18 and 19-20 years.[26] Resultantly, researchers have sought to identify risk factors for MUCL pathology to help mitigate time-loss injuries and preserve player function.

An abundance of modifiable and nonmodifiable risk factors have been demonstrated to have a potential impact on injury development to the MUCL. Modifiable risk factors across varying levels of play include, but are not limited, to pitch count,[5,14,42,51] pitch velocity,[5,10,27,37,51] glenohumeral range of motion (ROM),[1,19,52,53] and external rotation (ER)[4,20] and internal rotation (IR) shoulder strength.[20,28] Of these factors, glenohumeral rotational motion consistently continues to be discussed in the literature in regards to its relationship with MUCL injury development. Baseball players with an MUCL tear have also been found to have significant deficits in ROM at the shoulder.[19,53] For example, MUCL-injured players have 6° less of total shoulder rotational motion on the throwing arm when compared to an age matched healthy cohort, indicating less combined ER and IR on the throwing arm.[18] Similarly, a deficit in total shoulder rotation on the throwing arm increases the risk of elbow injury.[53] Greater shoulder IR ROM on the nonthrowing arm when compared to the throwing arm has been shown to be a risk factor for medial elbow instability and arm injuries.[11,45] However, these ROM risk factors do not account for osseous adaptations.

Humeral torsion describes the twist of the humerus and is defined as the angular difference between the orientation of the axis of the proximal humeral head and the epicondylar axis at the distal humerus.[12,30] Anatomic humeral retrotorsion (aHRT) refers to the posteromedial orientation of the humeral head axis with respect to the distal humeral epicondylar axis.[12] A recent meta-analysis assessing risk factors for MUCL injuries found that players who have a large side-to-side difference in aHRT (defined in this study as relative humeral retrotorsion [rHRT]) were more likely to sustain an MUCL injury when compared to healthy controls.[38] As such, it is imperative to account for rHRT when assessing glenohumeral rotational ROM. It has been shown that players exhibit a shift in rotational ROM when accounting for rHRT in both uninjured and injured baseball cohorts.[13,34,39] More specifically, glenohumeral ER (GER) deficits are more common than glenohumeral IR (GIR) deficits within the context of rHRT.[13,34,39] To date, no study has investigated shoulder motion within the context of rHRT in an MUCL-injured cohort simultaneously with uninjured matched controls.

Therefore, the purpose of this study was to determine if differences exist in HRT-corrected rotational motion between MUCL-injured and uninjured college baseball players. It was hypothesized that there would be significant differences in HRT-corrected rotational motion between MUCL-injured and uninjured college baseball players. More specifically, it was expected that there would be more ER loss in MUCL-injured baseball players when compared to an uninjured cohort.

Materials and methods

Study design

Data for this study was retrospectively pulled from a single surgeon database within a multisurgeon prospective clinical data registry. Prospective data collection started 10 March, 2022, and is currently ongoing. To answer these specific research questions data were exported on 4 February, 2025. All data were collected using REDCap (Research Electronic Data Capture; Vanderbilt University, Nashville, TN, USA) electronic data capture tool. REDCap is a secure, web-based software platform designed to support data capture for research studies, providing (1) an intuitive interface for validated data capture; (2) audit trails for tracking data manipulation and export procedures; (3) automated export procedures for seamless data downloads to common statistical packages; and (4) procedures for data integration and interoperability with external source.[22,23] All baseball players, despite injury status, read and signed an electronic informed consent form prior to enrollment in the study that was approved by The University of Texas Health Science Center at Houston.[31]

Participants

Baseball players with a diagnosed MUCL injury were matched by position, throwing arm, total years of baseball participation (within 3 years), year in school (within 1 year), and age at enrollment to players without an MUCL injury. All MUCL-injured baseball player data were collected at an outpatient sports medicine therapy clinic prior to a clinical evaluation with a board-certified, fellowship trained orthopedic surgeon (JEC). The diagnosis of an MUCL injury was based upon clinical examination by JEC and magnetic resonance imaging results. The control group (uninjured group) was recruited from 2 local National Collegiate Athletic Association (NCAA) Division I and III baseball programs. All uninjured player data were collected within the baseball training facility of each respective university.

Inclusion criteria for the MUCL-injured group were as follows: (1) clinical examination results were positive for MUCL injury, (2) competition at a college baseball program (NCAA-affiliated university, junior college, or National Association of Intercollegiate Athletics–affiliated university), (3) unable to participate in baseball with a primary complaint of elbow pain on the throwing arm, and (4) the injured arm was the same as the throwing arm. MUCL-injured players were excluded from the study if (1) there was a report of bilateral elbow pain or (2) there was a reported history of shoulder pathology on the injured arm within the last 6 months. To be included in the uninjured control cohort, players had (1) to compete in college baseball at the NCAA-affiliated university, (2) no history of elbow or shoulder injury in the previous 6 months that restricted athletic participation in all team activities at the time of testing, (3) no current shoulder or elbow injury or pain that limited restricted participation in all team activities at the time of testing, and 4) a documented Kerlan-Jobe Orthopaedic Clinic (KJOC) Score of > 79.[9] Studies using the KJOC in the assessment of uninjured baseball athletes have documented scores ranging between 90 and 95.[15,17,29] However, there is no true consensus on normative KJOC scores in an uninjured collegiate population, as other studies have shown mean scores of 87 and 81 in asymptomatic baseball athletes.[6,40] Therefore, a minimum KJOC score of 80 was used for screening eligibility for participation in this study.

Procedures

Demographic data, glenohumeral rotational ROM, and aHRT were collected using the same procedures for both cohorts. GIR and GER, and aHRT were collected by 2 examiners. Prior to data collection, intra-rater and inter-rater reliability for each of the measures were established.

Figure 1 – Measurement of (**A**) objective glenohumeral internal rotation and (**B**) objective glenohumeral external rotation.

Objective glenohumeral internal and external rotation range of motion

Objective GIR and GER motion were assessed passively on both arms utilizing a digital inclinometer, as similarly described by Wilk et al.[56] Participants were positioned supine on a treatment table in a hook-lying position with the legs positioned on a bolster to maintain a neutral alignment of the lumbar spine. A towel roll was placed under the participant's humerus to maintain scapular position in the coronal plane for standardization of testing. Examiner 1 stood at the head of the participant while moving the arm into 90° of shoulder abduction and 90° of elbow flexion while stabilizing the scapula. The scapula was stabilized by grasping the coracoid process anteriorly and the spine of the scapula posteriorly for both GIR and GER. Examiner 1 determined GIR and GER motion as the first point of scapular movement, and examiner 2 utilized a digital inclinometer to document the ROM. Examiner 2 aligned the inclinometer just below the shaft of the ulna and recorded the degrees of inclination. The digital inclinometer was zeroed to the vertical plane prior to the measurement. The recorded value in degrees represented the participants objective GIR and GER motion. For each participant, GER was

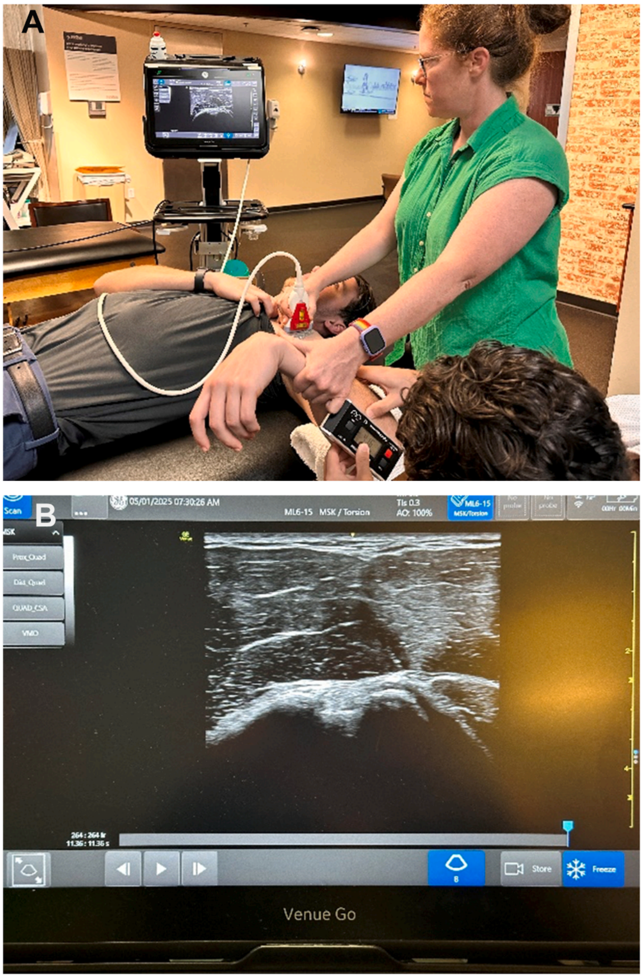

Figure 2 – Measurement of (**A**) anatomic humeral retrotorsion using a linear ultrasound probe placed over the anterior shoulder and (**B**) visualization of the deepest portion of the bicipital groove while the lesser and greater tubercle remain parallel.

measured first, followed by GIR. Each motion was measured twice and the mean of the 2 values were used for final analysis (Fig. 1). If there was a wide discrepancy in the 2 measures (> 3°), a third measurement was performed to ensure consistency, and the average of the closet 2 trials were used for analysis. Reliability for the 2 examiners were assessed using Intraclass Correlation Coefficients ($ICC_{2,1}$) with 95% confidence intervals (CIs) and standard error of measure (SEM). Examiner 1 intra-rater reliability results for objective GIR were $ICC_{2,1} = 0.93$, 95% CI [0.82-0.98], SEM = 2.32°, and for objective GER were $ICC_{2,1} = 0.90$, 95% CI [0.70-0.97], SEM = 2.54°. Examiner 2 intra-rater reliability results for objective GIR $ICC_{2,1} = 0.87$, 95% CI [0.64-0.95], SEM = 2.82°, and for objective GER were $ICC_{2,1} = 0.84$, 95% CI [0.56-0.95], SEM = 2.81°. Inter-rater reliability values for objective GIR were $ICC_{2,1} = 0.96$, 95% CI [0.81-0.99], SEM = 1.05°, and for objective GER were $ICC_{2,1} = 0.96$, 95% CI [0.86-0.99], SEM = 1.30°.

Table I – Calculations for rotational motion and humeral retrotorsion metrics.

Outcome measures	Calculations
MUCL-injured cohort	
Objective glenohumeral internal rotation (GIR) motion difference	Injured arm GIR motion - noninjured arm GIR motion
Objective glenohumeral external rotation (GER) motion difference	Injured arm GER motion - noninjured arm GER motion
Total range of motion (TROM) difference	Injured arm TROM - noninjured arm TROM
Relative humeral retrotorsion (rHRT)	Injured aHRT - noninjured aHRT
Uninjured cohort	
Objective glenohumeral internal rotation (GIR) motion difference	Throwing arm GIR motion - nonthrowing arm GIR motion
Objective glenohumeral external rotation (GER) motion difference	Throwing arm GER motion - nonthrowing arm GER motion
Total range of motion (TROM) difference	Throwing arm TROM - nonthrowing arm TROM
Relative humeral retrotorsion (rHRT)	Throwing aHRT - nonthrowing aHRT
All cohorts	
Total range of motion	GER ROM + GIR ROM
HRT-corrected glenohumeral internal rotation (GIR)	GIR motion difference - rHRT
HRT-corrected glenohumeral external rotation (GER)	GER motion difference + rHRT

aHRT, anatomic humeral retrotorsion; *MUCL*, medial ulnar collateral ligament.

Anatomic humeral retrotorsion

Anatomic HRT was assessed utilizing an indirect ultrasonographic technique that has been described[35] and validated by previous researchers.[33] Each player was positioned supine in hook lying on a standard treatment table with the legs positioned onto a bolster. Ultrasound gel (Cardinal Health, Dublin, OH, USA) was placed on a straight Matrix Linear 16-15 probe connected to the Venue Go R3 (GE HealthCare, Chicago, IL, USA) ultrasound machine. Examiner 1 placed the participant's shoulder in 90° of abduction with the elbow in 90° of flexion and neutral rotation and placed the probe over the anterior aspect of the participant's glenohumeral joint. A rolled towel was placed under the participant's humerus to maintain the scapula in the coronal plane. The probe was aligned perpendicular to the long axis of the humerus in the frontal plane. With the probe level (as designated by a bubble level on the face of the probe), examiner 1 rotated the humerus until the deepest part of bicipital groove was visualized and the apexes of the greater and lesser tubercles were parallel to the horizontal plane (Fig. 2). Examiner 2 then placed the digital inclinometer just below the shaft of the ulna to record the degrees of inclination. The digital inclinometer was zeroed to the vertical plane prior to the measurement. This process was repeated twice on both arms. The mean of the 2 values were used for final analysis; a third measure was performed if there was a wide discrepancy

Table II – Demographic characteristics for both the MUCL-injured and uninjured cohorts.

	MUCL cohort n = 35	Uninjured cohort n = 35	*P* value
Age, yr	20.2 ± 1.4	19.8 ± 1.2	.15
Height, cm*	184.5 ± 6.6	187.0 ± 5.7	.04
Weight, kg	90.8 ± 9.6	89.8 ± 7.6	.64
Body mass index,* kg/m^2	26.7 ± 2.2	25.6 ± 2.1	.03
Years of baseball participation	15.1 ± 2.3	14.7 ± 2.3	.41
KJOC score*	50.4 ± 17.8	95.1 ± 5.7	<.001
Throwing dominance			1.00
Right	31	31	
Left	4	4	
Player position			1.00
Pitcher	25	25	
Nonpitcher	10	10	
Level of competition*			<.001
Division I	12	35	
Division II	3	0	
Division III	8	0	
NAIA/junior college	12	0	

Yr, years; cm, centimeters; *kg*, kilograms; *m*, meter; *KJOC*, Kerlan-Jobe Orthopeadic Clinic Score; *NAIA*, National Association of Intercollegiate Athletics; *MUCL*, medial ulnar collateral ligament.
Continuous data are presented as means ± standard deviations while dichotomous variables are presented as counts.
* Denotes demographic differences between the groups.

Table III – Glenohumeral range of motion differences and HRT data for the MUCL-injured and uninjured cohorts.

	MUCL-injured cohort	Uninjured cohort
GER motion difference	9° ± 8°	12° ± 10°
GIR motion difference	−14° ± 8°	−16° ± 9°
TROM difference	−4° ± 11°	−4° ± 11°
Humeral retrotorsion values		
aHRT: throwing arm	14° ± 11°	13° ± 8°
aHRT: nonthrowing arm	32° ± 10°	31° ± 12°
rHRT	−18° ± 9°	−18° ± 10°

GER, glenohumeral external rotation; *GIR*, glenohumeral internal rotation; *TROM*, total range of motion; *aHRT*, anatomic humeral retrotorsion; *rHRT*, relative humeral retrotorsion; *MUCL*, medial ulnar collateral ligament.
Data are presented as means ± standard deviations.
There was no significant differences between any of the range of motion values presented in this table between the 2 cohorts ($P > .05$).

(> 3°) between the first 2 measures. Reliability for the 2 examiners were assessed using $ICC_{2,1}$ with 95% CIs and SEM. Examiner 1 intra-rater reliability results for aHRT was $ICC_{2,1} = 0.93$, 95% CI [0.76-0.98], SEM = 2.15°. Examiner 2 intra-rater reliability results for aHRT was $ICC_{2,1} = 0.91$, 95% CI [0.72-0.97], SEM = 2.08°. Inter-rater reliability values for aHRT was $ICC_{2,1} = 0.94$, 95% CI [0.85-0.97], SEM = 1.96°.

Data reduction

The raw data collected from both the objective rotational measures and aHRT were reduced. Calculations utilized in this study are described in Table I. This method is a data reduction technique to indicate the *direction* of motion loss in the context of rHRT. This data reduction technique does not result in a causal adjustment. It is important to note that the injured arm always represents the throwing arm in this study. When interpreting rHRT, a negative number indicates more aHRT on the injured (throwing arm) when compared to the noninjured (nonthrowing arm). In the case of uninjured athletes, aHRT was always assessed as the throwing arm (defined as the dominant arm) minus the nonthrowing arm (nondominant arm). In addition, when interpreting the HRT-corrected GIR and GER deficit, a negative number indicates a deficit, while a positive number indicates a gain in motion on the injured arm.

Statistical analysis

Baseline group demographics were compared to determine the similarities between the 2 groups. Continuous data were tested using an independent *t*-test, while nominal data were tested using a chi-square analysis. To test the main hypothesis of this study, we utilized a multivariate analysis of covariance (MANCOVA). The independent variables in this study were group allocation: MUCL-injured and uninjured cohorts. The dependent variables consisted of 2 motion measures: HRT-corrected GIR and GER. Body mass index (BMI) and level of competition (dummy coded as D1_dummy, D2_dummy, and D3_dummy, with NAIA/junior college as the reference) were included as covariates. Assumptions for MANCOVA were evaluated as follows: equality of covariance matrices was assessed using Box's M test (MANOVA without covariates), and equality of error variances for each dependent variable was assessed using Levene's test. Multivariate normality was evaluated via inspection of residuals. Follow-up univariate tests of between-subjects effects were conducted to determine which dependent variables contributed to significant multivariate effects. Partial eta squared (η^2) was reported as a measure of effect size using Cohen's conventions for interpretation: 0.2 for small, 0.5- 0.7 for moderate, and 0.8-1.0 for large changes.[8] All analyses were performed using available data; no imputation was conducted for missing values. Statistical significance was set at $\alpha = 0.05$. All data were analyzed using statistical package SPSS, version 29 (IBM Corp., Armonk, NY, USA).

Results

Equality of covariance matrices indicated no significant differences in the covariance matrices across cohorts ($P > .05$), supporting the assumption of homogeneity of covariance matrices. Levene's test indicated that equality of error variances for both dependent variables were met ($P > .05$). Participant baseline demographics are presented in Table II. Glenohumeral ROM and HRT data are presented in Table III. A total of 70 collegiate baseball players (35 MUCL-injured, 35 uninjured) were included in this study. One player in the MUCL group was missing data for KJOC score at evaluation.

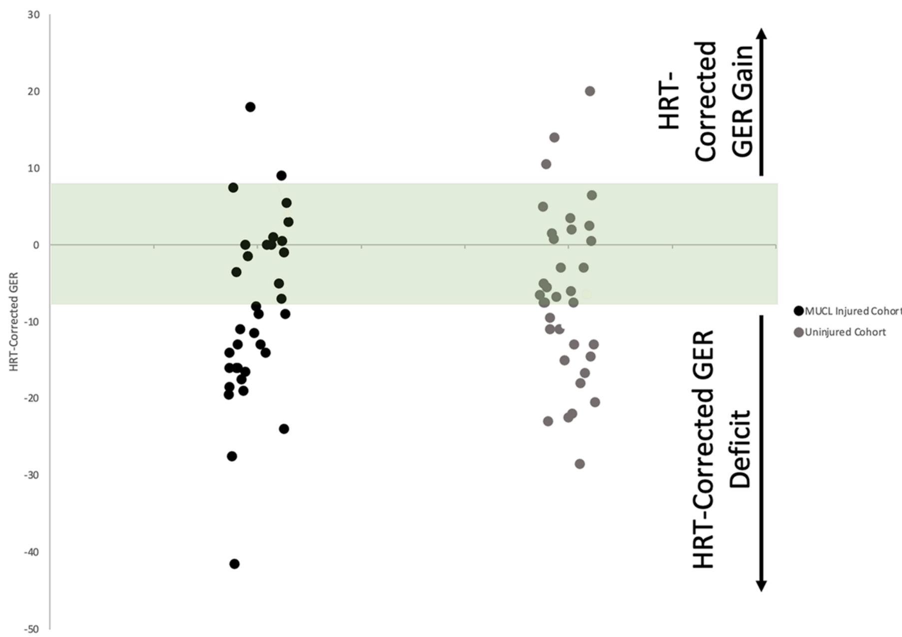

Figure 3 – A jitter plot representing no differences in HRT-corrected GER in degrees between an MUCL-injured and uninjured cohort for each of the 70 included baseball players. The *shaded green* represents a clinical threshold of < −7 and > 7 that represents HRT-corrected GER that is considered within normal limits as based off the clinical expertise of the authors. *HRT*, humeral retrotorsion; *GER*, glenohumeral external rotation; *MUCL*, medial ulnar collateral ligament.

Three players in the uninjured group were missing BMI at evaluation and were excluded from the analysis because BMI was used as a covariate. This also resulted in the removal of their 3 matched players from the MUCL cohort. Both cohorts were similar in baseline demographics ($P > .05$), except for height, BMI, KJOC score, and level of competition. Although both height and BMI differed significantly between the cohorts, BMI was selected as the covariate as it captures both weight and height in a single standardized measure of body size. Including both BMI and height would introduce redundancy and collinearity. The MUCL-injured cohort scored 44.7 points lower on the KJOC compared to the uninjured cohort ($P < .001$). There were no differences between age, weight, throwing limb dominance, player position, and year in sport between the 2 groups ($P > .05$). The MANCOVA indicated no significant multivariate effects of BMI, level of competition, or cohort on the combined outcomes of HRT-corrected GER and HRT-corrected GIR (all Pillai's Trace $P > .05$, partial $\eta^2 \leq 0.019$). Given the nonsignificant multivariate results and minimal effect sizes, the univariate tests of between-subjects effects were not interpreted. Estimated marginal means, adjusted for BMI, and level of competition for HRT-corrected GER in the MUCL cohort was −9.99° (SE = 2.51; 95% CI: −15.02, −4.96) and −5.45° (SE = 2.51; 95% CI: −10.48, −0.42) for the uninjured cohort. Estimated marginal means, adjusted for BMI, and level of competition for HRT-corrected GIR in the MUCL cohort was 5.01° (SE = 2.46; 95% CI: 0.09, 9.94) and 2.21° (SE = 2.46; 95% CI: −2.71, 7.14) for the uninjured cohort. Figs. 3 and 4 depict the distribution of the data when considering HRT-corrected GER and GIR scores for each of the 70 college baseball players in each of the 2 cohorts.

Discussion

After accounting for BMI and level of competition, cohort membership (MUCL-injured vs. uninjured) was not significantly related to HRT-corrected motion. We have failed to reject the null hypothesis, as there were no significant group differences between the MUCL-injured and uninjured college baseball cohorts. The lack of significant differences between cohorts may reflect the homogeneity of collegiate-level baseball players in terms of training exposure, as well as the use of HRT-corrected measures, which minimize variability from osseous adaptation and may reduce between-group differences. Deficits in GER, as opposed to GIR when correcting for HRT in both injured and uninjured college baseball players are present, with average symmetrical total ROM differences in both cohorts. The findings of this paper align with previously published literature, as HRT-corrected GER deficits are present in both injured and uninjured baseball players.[13,34,39] These findings should challenge researchers and clinicians to consider that the widely accepted risk factor of GIR differences in the baseball athlete might not be as prevalent as we once thought. In addition, since HRT-corrected GER deficit are present in both injured MUCL and uninjured baseball players, attention should be placed on identifying risk profiles including both subjective and objective information for these athletes instead of a single risk factor, as sustaining an injury is a multifactorial process.[32,47]

Normal adaptations on the throwing arm in baseball players include increased GER with a decrease in GIR when compared to the nonthrowing arm.[24] One plausible

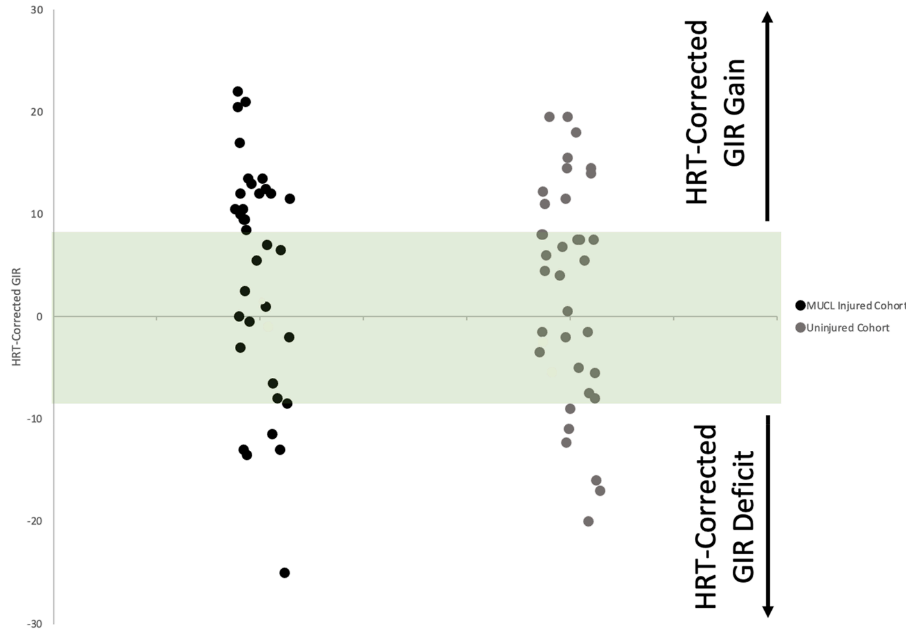

Figure 4 — A jitter plot representing no differences in HRT-corrected GIR in degrees between an MUCL-injured and uninjured cohort for each of the 70 included baseball players. The *shaded green* represents a clinical threshold of < −7 and > 7 that represents HRT-corrected GIR that is considered within normal limits as based off the clinical expertise of the authors. *HRT*, humeral retrotorsion; *GIR*, glenohumeral internal rotation; *MUCL*, medial ulnar collateral ligament.

contribution for these adaptations is the osseous changes that occur to the humerus as a result of throwing.[50] It is well documented that aHRT is greater on the throwing arm when compared to the nonthrowing arm in baseball players, with a difference of anywhere between 10° and 20° between arms.[21,50] As such, an effort has been made to account for rHRT when quantifying deficits in rotational glenohumeral ROM. In a clinical scenario, when not accounting for rHRT, clinicians will typically observe GIR differences in both an MUCL-injured and uninjured baseball cohort. However, research has shown that up to 65% of GIR on the throwing arm is explained by aHRT,[25] posing an explanation for observed GIR differences in baseball players between the throwing and nonthrowing arms.[44,46,54] When accounting for aHRT, a shift in motion becomes present where deficits in GER are more common as opposed to GIR. To further support this notion, a recent systematic review demonstrated soft tissue restrictions in GER are more commonly observed when accounting for rHRT.[36] Previous reports have suggested that GIR differences can increase injury risk when those differences range between −13° and −25° depending on the baseball athlete's level of play.[44-46,54] Interestingly, in this study, when motion is interpreted within the context of rHRT, 87% of the injured cohort and 89% of the uninjured cohort did not have a GIR difference (or classically known as GIRD). As a result, clinicians must consider rHRT when managing both injured and uninjured baseball athletes to adequately determine the directionality of glenohumeral rotational motion loss.

The authors of this study would like to highlight an important note that retrotorsion does not explain a 1:1 ratio for motion[25]; that is to say, in no scenarios should clinicians expect a perfect 1° increase in GER and a 1° decrease in GIR for every 1° increase of rHRT. The data reduction technique used in our study simply implies the directionality in which motion loss is occurring, and the end goal should be to address this directional motion loss to restore total arc of motion within 5°.[55]

ROM has been a heavily discussed topic in the baseball athlete for the past 3 decades with aHRT making an entrance within the early 2000s. This study was unable to define a threshold for pathological HRT-corrected GER and GIR, specifically in collegiate baseball athletes with MUCL injuries, as no differences were observed between groups. This is not to say that ROM is not as important as once thought in these 2 cohorts of athletes, but instead lends researchers and clinicians to consider a combination of factors in order to better understand injury risk and mitigation. Injury risk mitigation requires a clinical decision-making process encompassing a complex, multifactorial system.[2] In conjunction with traditional monitoring of clinical objective measures, the integration of subjective outcomes reporting and playing level-specific education regarding participation and throwing volume may also be appropriate, as athletes are seen as a complex adaptive system.[32] For example, in a study by Bullock et al organizational risk profiling and education appear to decrease short-term professional pitching-related injury risk by 33-38%.[3] Similarly, Stern et al describes an athlete's resistance to injury as a nonlinear dynamic system. This system has 2 coexisting states in which an athlete is either healthy or injured, with a dangerous point between the 2 states that can quickly send a healthy athlete into an injured state. Within this system, an athlete has determinants of health that may drive injury risk, such as motion, strength, load, fear, coping skills, self-efficacy, stress, and other psychosocial factors.[47] Because of this dynamic system and the ever-changing physical and psychological profiles an athlete endures over the course of a season, risk factors that are typically used prior to a season do not fully demonstrate how an athlete may change over the course of a season, both subjectively and objectively. Therefore, it is imperative to focus on broader sampling and serial testing of both subjective and objective testing over time, in order to fully understand the dynamic changes that an athlete may experience and understand how to clinically manage that athlete.[32,47]

It is important to note the limitations of this study. First, this study investigated college baseball players. As such, the outcomes of this study may differ by level of play. These data should not be generalized across different levels of play and even diagnosis when investigating the association between HRT-corrected rotational motion deficits and the presence of injury. Second, left-handed throwers were included in this study. It should be noted that left-handed throwers tend to have smaller rHRT than their right-handed throwing counterparts.[48] The inclusion of left-handed throwers could alter the rHRT differences calculated, and in turn, alter the HRT-corrected ROM measures. The equal distribution of left- and right-handed throwers per group should mitigate this effect through equal distribution. Third, our approach to accounting for humeral retroversion indicates the direction of motion loss rather than quantifying exact anatomical changes and does not assume a 1:1 relationship between torsion and ROM. Consequently, the results should be interpreted as patterns of motion limitation rather than precise casual biomechanical corrections. Fourth, a formal a priori power analysis was not performed for the current analytic design, which limits our ability to determine whether nonsignificant findings reflect true absence of effect vs. insufficient sample size. Finally, while the authors were able to match the groups we were unable to match by level of competition within collegiate baseball. Control participants were drawn from a single geographic region for convenience, whereas cases came from a broader area, which may introduce selection bias and limit generalizability. Future studies should consider matching controls by college or conference to better account for regional and competition-level differences. It is currently unknown whether or not HRT-corrected motion differs between level of play in collegiate baseball.

Conclusion

MUCL-injured and uninjured collegiate baseball players demonstrate more aHRT on the throwing arm when compared to the nonthrowing arm, and HRT-corrected GER deficits are more prevalent than HRT-corrected GIR deficits. These findings are in contrast to previous literature that does not take into account rHRT[11,19,45,53]; however, researchers that have accounted for rHRT in their soft tissue motion have reported similar findings regarding HRT-corrected GER deficits.[13,34,39] The study highlights the importance of considering osseous adaptations when examining rotational ROM in all baseball athletes, despite injury status. Since HRT-corrected GER deficits occur in both injured and uninjured cohorts, a comprehensive injury risk mitigation profile, incorporating multiple evidence-informed metrics, is warranted in the care of baseball athletes.

Disclaimers:

Funding: The authors have no financial disclaimer to report.

Conflicts of interest: Dr. Conway reports royalty or license from Arthrex; nonconsulting fees from Arthrex, education payments from Medinc or Texas, Pylant Medical, and Arthrex; none of these disclosures influence the contents discussed within this manuscript. The other authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

REFERENCES

1. Agresta CE, Krieg K, Freehill MT. Risk factors for baseball-related arm injuries: a systematic review. Orthop J Sports Med 2019;7:1–13. https://doi.org/10.1177/2325967119825557.
2. Ardern CL, Glasgow P, Schneiders A, Witvrouw E, Clarsen B, Cools A, et al. 2016 consensus statement on return to sport from the first world congress in sports physical therapy, bern. Br J Sports Med 2016;50:853–64. https://doi.org/10.1136/bjsports-2016-096278.
3. Bullock GS, Thigpen CA, Collins GS, Arden NK, Noonan TJ, Kissenberth MJ, et al. Organizational risk profiling and education associated with reduction in professional pitching arm injuries: a natural experiment. JSES Rev Rep Tech 2023;3:295–302. https://doi.org/10.1016/j.xrrt.2023.03.005.
4. Byram IR, Bushnell BD, Dugger K, Charron K, Harrell FE Jr., Noonan TJ. Preseason shoulder strength measurements in professional baseball pitchers: identifying players at risk for injury. Am J Sports Med 2010;38:1375–82. https://doi.org/10.1177/0363546509360404.
5. Chalmers PN, Erickson BJ, Ball B, Romeo AA, Verma NN. Fastball pitch velocity helps predict ulnar collateral ligament reconstruction in major league baseball pitchers. Am J Sports Med 2016;44:2130–5. https://doi.org/10.1177/0363546516634305.
6. Chasse P, Bullock GS, Schmitt AC, Little BA, Diehl LH, Butler RJ. The relationship between trunk rotation, upper quarter dynamic stability, and the kerlan-jobe orthopaedic clinic overhead athlete shoulder and elbow score in division i collegiate pitchers. Int J Sports Physther 2018;13:819–27.
7. Ciccotti MG, Pollack KM, Ciccotti MC, D'Angelo J, Ahmad CS, Altchek D, et al. Elbow injuries in professional baseball: epidemiological findings from the major league baseball injury surveillance system. Am J Sports Med 2017;45:2319–28. https://doi.org/10.1177/0363546517706964.
8. Cohen J. Statistical power analysis for the behavioral sciences. Lawrence Erlbaum Associates, Inc: Hillsdale, NJ; 1988.
9. Croci J, Nicknair J, Goetschius J. Early sport specialization linked to throwing arm function and upper extremity injury history in college baseball players. Sports Health 2021;13:230–6. https://doi.org/10.1177/1941738120986555.
10. DeFroda SF, Kriz PK, Hall AM, Zurakowski D, Fadale PD. Risk stratification for ulnar collateral ligament injury in major league baseball players: a retrospective study from 2007 to 2014. Orthop J Sports Med 2016;4:2325967115627126. https://doi.org/10.1177/2325967115627126.

11. Dines JS, Frank JB, Akerman M, Yocum LA. Glenohumeral internal rotation deficits in baseball players with ulnar collateral ligament insufficiency. Am J Sports Med 2009;37:566–70. https://doi.org/10.1177/0363546508326712.
12. Edelson G. Variations in the retroversion of the humeral head. J Shoulder Elbow Surg 1999;8:142–5.
13. Entler K, Kruseman JK, Kennedy SM, Conway JE, Reyes GJ, Garrison JC, et al. The role of humeral torsion on glenohumeral rotation in injured baseball players. Orthop J Sports Med 2024;12:23259671241260084. https://doi.org/10.1177/23259671241260084.
14. Erickson BJ, Chalmers PN, Axe MJ, Romeo AA. Exceeding pitch count recommendations in little league baseball increases the chance of requiring tommy john surgery as a professional baseball pitcher. Orthop J Sports Med 2017;5:2325967117695085. https://doi.org/10.1177/2325967117695085.
15. Faherty MS, Plata A, Chasse P, Zarzour R, Sell TC. Upper extremity musculoskeletal characteristics and the kerlan-jobe orthopaedic clinic questionnaire score in collegiate baseball athletes. J Athl Train 2019;54:945–52. https://doi.org/10.4085/1062-6050-81-18.
16. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. Am J Sports Med 1995;23:233–9.
17. Fronek J, Yang JG, Osbahr DC, Pollack KM, ElAttrache NS, Noonan TJ, et al. Shoulder functional performance status of minor league professional baseball pitchers. J Shoulder Elbow Surg 2015;24:17–23. https://doi.org/10.1016/j.jse.2014.04.019.
18. Garrison JC, Arnold A, Macko MJ, Conway JE. Baseball players diagnosed with ulnar collateral ligament tears demonstrate decreased balance compared to healthy controls. J Orthop Sports Phys Ther 2013;43:752–8. https://doi.org/10.2519/jospt.2013.4680.
19. Garrison JC, Cole MA, Conway JE, Macko MJ, Thigpen C, Shanley E. Shoulder range of motion deficits in baseball players with an ulnar collateral ligament tear. Am J Sports Med 2012;40:2597–603. https://doi.org/10.1177/0363546512459175.
20. Garrison JC, Johnston C, Conway JE. Baseball players with ulnar collateral ligament tears demonstrate decreased rotator cuff strength compared to healthy controls. Int J Sports Phys Ther 2015;10:476–81.
21. Greenberg EM, Fernandez-Fernandez A, Lawrence JT, McClure P. The development of humeral retrotorsion and its relationship to throwing sports. Sports Health 2015;7:489–96. https://doi.org/10.1177/1941738115608830.
22. Harris PA, Taylor R, Minor BL, Elliott V, Fernandez M, O'Neal L, et al. The redcap consortium: building an international community of software platform partners. J Biomed Inform 2019;95:103208. https://doi.org/10.1016/j.jbi.2019.103208.
23. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. A metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform 2009;42:377–81. https://doi.org/10.1016/j.jbi.2008.08.010.
24. Hellem A, Shirley M, Schilaty N, Dahm D. Review of shoulder range of motion in the throwing athlete: distinguishing normal adaptations from pathologic deficits. Curr Rev Musculoskelet Med 2019;12:346–55. https://doi.org/10.1007/s12178-019-09563-5.
25. Helmkamp JK, Bullock GS, Rao A, Shanley E, Thigpen C, Garrigues GE. The relationship between humeral torsion and arm injury in baseball players: a systematic review and meta-analysis. Sports Health 2020;12:132–8. https://doi.org/10.1177/194173811990.
26. Hodgins JL, Vitale M, Arons RR, Ahmad CS. Epidemiology of medial ulnar collateral ligament reconstruction: a 10-year study in New York state. Am J Sports Med 2016;44:729–34. https://doi.org/10.1177/0363546515622407.
27. Keller RA, Marshall NE, Guest JM, Okoroha KR, Jung EK, Moutzouros V. Major league baseball pitch velocity and pitch type associated with risk of ulnar collateral ligament injury. J Shoulder Elbow Surg 2016;25:671–5. https://doi.org/10.1016/j.jse.2015.12.027.
28. Kennedy SM, Sheedy P, Klein B, Gist M, Hannon JP, Conway JE, et al. Differences in shoulder internal rotation strength between baseball players with ulnar collateral ligament reconstruction and healthy controls. Orthop J Sports Med 2021;10:23259671211065025. https://doi.org/10.1177/23259671211065025.
29. Kraeutler MJ, Ciccotti MG, Dodson CC, Frederick RW, Cammarota B, Cohen SB. Kerlan-jobe orthopaedic clinic overhead athlete scores in asymptomatic professional baseball pitchers. J Shoulder Elbow Surg 2013;22:329–32. https://doi.org/10.1016/j.jse.2012.02.010.
30. Krahl VE. The torsion of the humerus: its localization, cause and duration in man. J Anat 1947;80:275–315.
31. Lawrence CE, Dunkle L, McEver M, Israel T, Taylor R, Chiriboga G, et al. A redcap-based model for electronic consent (econsent): moving toward a more personalized consent. J Clin Transl Sci 2020;3:345–53. https://doi.org/10.1017/cts.2020.30.
32. Montull L, Slapšinskaitė-Dackevičienė A, Kiely J, Hristovski R, Balagué N. Integrative proposals of sports monitoring: subjective outperforms objective monitoring. Sports Med Open 2022;8:41. https://doi.org/10.1186/s40798-022-00432-z.
33. Myers JB, Oyama S, Clarke JP. Ultrasonographic assessment of humeral retrotorsion in baseball players: a validation study. Am J Sports Med 2012;40:1155–60. https://doi.org/10.1177/036354651243.
34. Myers JB, Oyama S, Goerger BM, Rucinski TJ, Blackburn JT, Creighton RA. Influence of humeral torsion on interpretation of posterior shoulder tightness measures in overhead athletes. Clin J Sport Med 2009;19:366–71. https://doi.org/10.1097/JSM.0b013e3181b544f6.
35. Noonan TJ, Shanley E, Bailey LB, Wyland DJ, Kissenberth MJ, Hawkins RJ, et al. Professional pitchers with glenohumeral internal rotation deficit (gird) display greater humeral retrotorsion than pitchers without gird. Am J Sports Med 2015;43:1448–54. https://doi.org/10.1177/0363546515575020.
36. Paul RW, Sirch FR, Vata A, Zhu E, Alberta FG, Erickson BJ, et al. Chronic adaptations of the shoulder in baseball pitchers: a systematic review. Am J Sports Med 2025;53:2984–94. https://doi.org/10.1177/03635465251317202.
37. Prodromo J, Patel N, Kumar N, Denehy K, Tabb LP, Tom J. Pitch characteristics before ulnar collateral ligament reconstruction in major league pitchers compared with age-matched controls. Orthop J Sports Med 2016;4:2325967116653946. https://doi.org/10.1177/2325967116653946.
38. Reiman MP, Walker MD, Peters S, Kilborn E, Thigpen CA, Garrigues GE. Risk factors for ulnar collateral ligament injury in professional and amateur baseball players: a systematic review with meta-analysis. J Shoulder Elbow Surg 2019;28:186–95. https://doi.org/10.1016/j.jse.2018.08.018.
39. Reuther KE, Sheridan S, Thomas SJ. Differentiation of bony and soft-tissue adaptations of the shoulder in professional baseball pitchers. J Shoulder Elbow Surg 2018;27:1491–6. https://doi.org/10.1016/j.jse.2018.02.053.
40. Rich A, Stickley L. Corrleation between the kerlan-jobe orthopedic clinic screen and subacromial impingment test-item cluster in collegiate baseball pitchers: a pilot study. Int J Sports Phys Ther 2020;15:1080–9. https://doi.org/10.26603/ijspt20201080.
41. Rothermich MA, Conte SA, Aune KT, Fleisig GS, Cain EL Jr., Dugas JR. Incidence of elbow ulnar collateral ligament surgery in collegiate baseball players. Orthop J Sports Med 2018;6:2325967118764657. https://doi.org/10.1177/2325967118764657.

42. Salamh P, Jones E, Bashore M, Liu X, Hegedus EJ. Injuries and associated risk factors of the shoulder and elbow among adolescent baseball pitchers: a systematic review and meta-analysis. Phys Ther Sport 2020;43:108–19. https://doi.org/10.1016/j.ptsp.2020.02.013.
43. Saper MG, Pierpoint LA, Liu W, Comstock RD, Polousky JD, Andrews JR. Epidemiology of shoulder and elbow injuries among United States high school baseball players: school years 2005-2006 through 2014-2015. Am J Sports Med 2018;46:37–43. https://doi.org/10.1177/0363546517734172.
44. Shanley E, Kissenberth MJ, Thigpen CA, Bailey LB, Hawkins RJ, Michener LA, et al. Preseason shoulder range of motion screening as a predictor of injury among youth and adolescent baseball pitchers. J Shoulder Elbow Surg 2015;24:1005–13. https://doi.org/10.1016/j.jse.2015.03.012.
45. Shanley E, Rauh MJ, Michener LA, Ellenbecker TS, Garrison JC, Thigpen CA. Shoulder range of motion measures as risk factors for shoulder and elbow injuries in high school softball and baseball players. Am J Sports Med 2011;39:1997–2006. https://doi.org/10.1177/0363546511408876.
46. Shitara H, Kobayashi T, Yamamoto A, Shimoyama D, Ichinose T, Tajika T, et al. Prospective multifactorial analysis of preseason risk factors for shoulder and elbow injuries in high school baseball pitchers. Knee Surg Sports Traumatol Arthrosc 2017;25:3303–10. https://doi.org/10.1007/s00167-015-3731-4.
47. Stern BJ, Hegedus EJ, Lai YC. Injury prediction as a non-linear system. Phys Ther Sport 2020;41:43–8. https://doi.org/10.1016/j.ptsp.2019.10.010.
48. Takenaga T, Goto H, Sugimoto K, Tsuchiya A, Fukuyoshi M, Nakagawa H, et al. Left-handed skeletally mature baseball players have smaller humeral retroversion in the throwing arm than right-handed players. J Shoulder Elbow Surg 2017;26:2187–92. https://doi.org/10.1016/j.jse.2017.07.014.
49. Trofa DP, Obana KK, Swindell HW, Shiu B, Noticewala MS, Popkin CA, et al. Increasing burden of youth baseball elbow injuries in us emergency departments. Orthop J Sports Med 2019;7:2325967119845636. https://doi.org/10.1177/2325967119845636.
50. Whiteley RJ, Ginn KA, Nicholson LL, Adams RD. Sports participation and humeral torsion. J Orthop Sports Phys Ther 2009;39:256–63. https://doi.org/10.2519/jospt.2009.2821.
51. Whiteside D, Martini DN, Lepley AS, Zernicke RF, Goulet GC. Predictors of ulnar collateral ligament reconstruction in major league baseball pitchers. Am J Sports Med 2016;44:2202–9. https://doi.org/10.1177/0363546516643812.
52. Whitt S, Craig Garrison J, Creed K, Giesler L, Conway JE. Baseball players diagnosed with ulnar collateral ligament tears demonstrate greater side to side differences in passive glenohumeral abduction range of motion compared to healthy controls. Int J Sports Phys Ther 2019;14:353–8. https://doi.org/10.26603/ijspt20190353.
53. Wilk KE, Macrina LC, Fleisig GS, Aune KT, Porterfield RA, Harker P, et al. Deficits in glenohumeral passive range of motion increase risk of elbow injury in professional baseball pitchers: a prospective study. Am J Sports Med 2014;42:2075–81. https://doi.org/10.1177/0363546514538391.
54. Wilk KE, Macrina LC, Fleisig GS, Aune KT, Porterfield RA, Harker P, et al. Deficits in glenohumeral passive range of motion increase risk of shoulder injury in professional baseball pitchers: a prospective study. Am J Sports Med 2015;43:2379–85. https://doi.org/10.1177/0363546514538391.
55. Wilk KE, Macrina LC, Fleisig GS, Porterfield R, Simpson CD 2nd, Harker P, et al. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. Am J Sports Med 2011;39:329–35. https://doi.org/10.1177/0363546510384223.
56. Wilk KE, Reinold MM, Macrina LC, Porterfield R, Devine KM, Suarez K, et al. Glenohumeral internal rotation measurements differ depending on stabilization techniques. Sports Health 2009;1:131–6. https://doi.org/10.1177/0363546514538391.