J Shoulder Elbow Surg (2021) 30, 290–297

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Relationship between humeral retroversion and baseball positions during elementary and junior-high school

Akihiko Hasegawa, MD, PhD[a], Teruhisa Mihata, MD, PhD[a,*], Yasuo Itami, MD, PhD[a], Atsushi Takeda, PT[b], Masashi Neo, MD, PhD[a]

[a]*Department of Orthopedic Surgery, Osaka Medical College, Takatsuki, Japan*
[b]*Department of Rehabilitation, First Towakai Hospital, Takatsuki, Japan*

Background: Humeral retroversion is greater in the dominant shoulder than in the nondominant shoulder in baseball players. However, the effect of different baseball positions during childhood on humeral retroversion remains unknown. The purpose of this study was to investigate the following: (1) the relationship between humeral retroversion and baseball positions played during elementary and junior-high schools; (2) the association between humeral retroversion and the prevalence of pain during the medical checkup and self-reported history of injuries in the dominant shoulder or elbow.
Methods: We enrolled 149 male high-school baseball players who started playing baseball in elementary school. The subjects were classified into 3 groups according to their baseball positions in elementary and junior-high schools. All participants completed questionnaires regarding their current and past positions, current incidence and history of injuries in their shoulder or elbow joints, and the age they started playing baseball. Shoulder range of motion, humeral retroversion on ultrasonographic-assisted measurement, and the association between humeral retroversion and shoulder and elbow pain were evaluated.
Results: Humeral retroversion was significantly greater in the dominant shoulder than in the nondominant shoulder in all groups ($P <$ .001). In addition, humeral retroversion in the dominant shoulder was significantly greater in players who were pitchers in both elementary and junior-high schools than in those who were fielders during both periods (96.2° and 89.4°, respectively; $P =$ .02). Humeral retroversion in the dominant shoulder was positively correlated ($P =$ .005, $r = 0.23$) with the length of career as a pitcher during elementary and junior-high schools. Humeral retroversion was not correlated with the prevalence of pain during the medical checkup or self-reported history of injuries in the dominant shoulder or elbow (P values ranging from 0.09-0.99).
Conclusion: These results suggest that playing baseball as a pitcher during elementary school and junior-high school affects the increase in humeral retroversion in the dominant shoulder. Increased humeral retroversion in the dominant shoulder by repetitive throwing motion is an adaptive change, rather than a pathologic change.
Level of evidence: Level III; Cross-Sectional Design; Epidemiology Study

Keywords: baseball position; humeral retroversion; pitcher; dominant shoulder; range of motion; fielder

Humeral retroversion is defined as the rotational angle of the proximal humerus relative to the distal humerus.[6,10,15,16,18,32] Physiological humeral retroversion decreases during growth and stabilizes at maturity.[5,7] Edelson showed that the mean humeral retroversion in

This study protocol was approved by the Institutional Review Board at Osaka Medical College (no. 1338).

*Reprint requests: Teruhisa Mihata, MD, PhD, Department of Orthopedic Surgery, Osaka Medical College, 2-7 Daigaku-machi, Takatsuki, Osaka 569-8686, Japan.

E-mail address: tmihata@osaka-med.ac.jp (T. Mihata).

1058-2746/$ - see front matter © 2020 Journal of Shoulder and Elbow Surgery Board of Trustees. All rights reserved.
https://doi.org/10.1016/j.jse.2020.05.018

humans decreases by 48° between birth and skeletal maturity at 16-19 years of age.[7] In throwing athletes, the external forces caused by repetitive throwing are thought to restrict physiological de-rotation of the humerus,[25,32] such that humeral retroversion is greater in the dominant shoulder than in the nondominant shoulder in baseball players.[6,15,16,23,32] This side-to-side difference in humeral retroversion has been reported in elementary school,[13,32] junior-high school,[32] high school,[15,18] college,[20,24,29] and professional[6,31] baseball players.

Previous studies reported that side-to-side difference in humeral retroversion becomes evident from the fourth to the fifth grade,[13,32] and the changes in humeral retroversion associated with throwing in baseball players are already completed by high school.[15,21] Recently, Nakase et al[18] reported a significant negative correlation between humeral retroversion on the dominant side and the age when the players started playing baseball. Takenaga et al[28] reported that players who started playing baseball after 11 years of age demonstrated significantly smaller humeral retroversion in the throwing arm than those who started playing baseball before age 11. Because of the occurrence of growth spurt after the age of 11, throwing is likely to exhibit a more significant influence on the bony structure of those who started playing baseball before the age of 11 than those who started playing baseball after the age of 11.[32] To date, however, it remains unclear whether the positions played during elementary school and junior-high school affect humeral retroversion. Because pitchers throw more frequently than fielders during baseball games,[3] increasing the frequency of pitching during elementary school and junior-high school may increase humeral retroversion in the dominant shoulder.

Increased humeral retroversion in the dominant shoulder has been considered an adaptive change in baseball players.[15,31] However, some studies have recently reported a relationship between the risk of throwing injury and humeral retroversion. Polster et al[23] reported a strong relationship between lower degrees of dominant humeral retroversion and more severe throwing injuries in professional baseball pitchers. Noonan et al[19] reported that increased adaptive humeral retroversion is protective against shoulder injuries but a harmful contributor of elbow injuries in professional pitchers. On the contrary, Oyama et al[22] reported that shoulder rotation range of motion (ROM) or humeral retroversion at preseason did not predict the risk of throwing-related injury of the upper extremity in high school baseball players. Because of inconsistency in the findings of previous studies, the association between increased humeral retroversion in the throwing arm and throwing injuries remains inconclusive.

Hence, the objectives of this study were to investigate the following: (1) the effect of baseball positions played during elementary and junior-high schools on humeral retroversion in high-school baseball players; (2) the association between humeral retroversion and the prevalence of pain during the medical checkup and self-reported history of injuries in the dominant shoulder or elbow. We hypothesized that (1) humeral retroversion would be greater in baseball players who were pitchers in elementary school and junior-high school than in those who were fielders; (2) the increased humeral retroversion in the dominant shoulder by repetitive throwing motion does not cause shoulder and elbow pain.

Materials and methods

Subjects and study design

This is a retrospective cross-sectional epidemiology study. In total, 149 male baseball players in their first year of high-school (age: mean, 15.4 years; range, 15-16 years) who were medically examined during the annual team medical checkup were enrolled in this study. The exclusion criteria were any history of fracture or previous surgery to the shoulder or elbow joints. All 149 players had started playing baseball in elementary school. The mean age at which subjects began playing baseball was 8.0 years (range, 4-12 years). We classified the subjects into 3 groups based on the positions played during baseball in elementary and junior-high schools, as follows: group 1 players (n = 34) were pitchers in both elementary and junior-high schools; group 2 players (n = 48) were pitchers in either elementary school or junior-high school; and group 3 players (n = 67) were fielders in both elementary school and junior-high school. The demographic data of the subjects are shown in Table I.

The goals and components of the study were explained to all participants and their parents. The participants and their guardians reviewed and signed an informed consent form. All participants completed questionnaires with the cooperation of their families regarding their baseball career, including the age when started playing baseball, current and past positions in elementary school and junior-high school, current shoulder or elbow pain during baseball, and history of injuries in the shoulder or elbow joint. In addition, all subjects were examined for shoulder ROM and humeral retroversion bilaterally using ultrasonography.[15,18]

Assessment of shoulder joint

The evaluated variables of shoulder ROM were as follows: (1) external rotation, (2) internal rotation, and (3) the total arc of rotation. The examiner assessed passive shoulder ROM in the horizontal plane using a conventional technique recommended by the American Academy of Orthopaedic Surgeons.[2] Neutral rotation was defined as the position at which the long axis of the forearm was perpendicular to the trunk. The examiner stabilized the scapula during ROM measurements by holding the subject's acromion and coracoid process. The ends of the range of external and internal rotations were defined by visual or tactual observation of a movement in the scapula via the subject's acromion and coracoid process by the examiner. The second examiner placed a digital inclinometer (accuracy, 0.1°, Smart Tool; M-D Building Products, Oklahoma City, OK, USA) on the palmar side of the forearm to measure the degree of rotation away from the horizontal plane (trunk) as previously described (Fig. 1).[15,18] The

Table I Subject demographics

	Group 1 (pitcher) (n = 34)	Group 2 (pitcher/fielder) (n = 48)	Group 3 (fielder) (n = 67)	Total (n = 149)
Age, yr	15.4 ± 0.5	15.4 ± 0.5	15.4 ± 0.5	15.4 ± 0.5
Age when subject started playing baseball, yr	7.6 ± 1.5	8.1 ± 1.4	8.1 ± 1.7	8.0 ± 1.6
Height, cm	173.4 ± 4.9	170.7 ± 4.9*	168.8 ± 5.2†	170.5 ± 5.3
Weight, kg	68.5 ± 7.5	66.5 ± 7.0	63.5 ± 7.8‡	65.6 ± 7.7
BMI	22.7 ± 1.7	22.8 ± 2.2	22.3 ± 2.1	22.5 ± 2.1

BMI, body mass index.
* Significantly less ($P = .042$) than value for group 1.
† Significantly less ($P < .001$) than value for group 1.
‡ Significantly less ($P = .006$) than value for group 1.

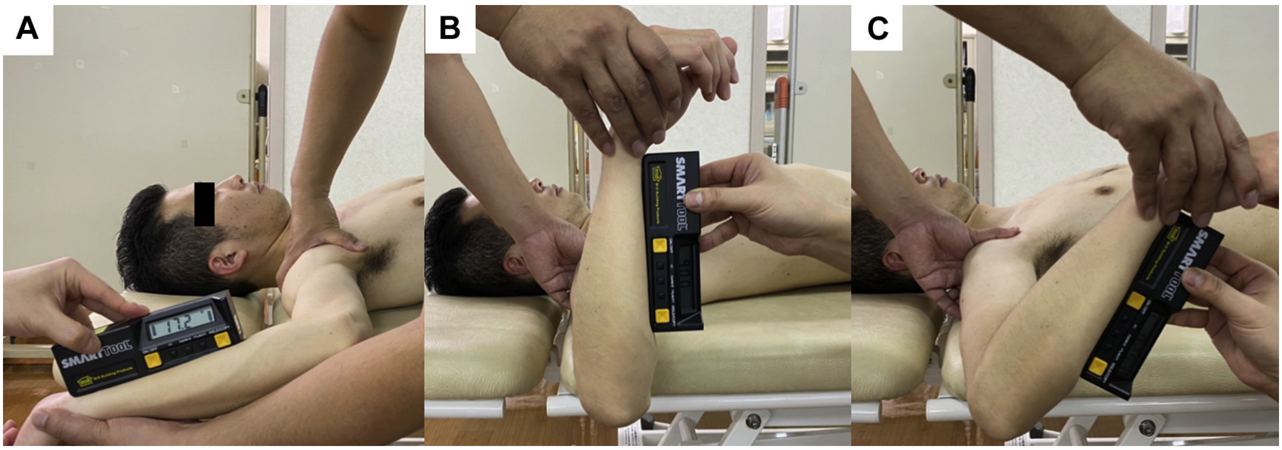

Figure 1 The shoulder range of motion in the horizontal plane was measured using a conventional technique recommended by the American Academy of Orthopaedic Surgeons.[2] Neutral rotation was defined as the position at which the long axis of the forearm was perpendicular to the trunk. The degree of rotation away from the horizontal plane (trunk) was measured using a digital inclinometer (Smart Tool, M-D Building Products; accuracy, 0.1°). (**A**) External rotation; (**B**) neutral rotation; (**C**) internal rotation.

angles from the neutral rotation to each endpoint were calculated. All measurements of shoulder ROM were bilaterally taken 3 times by the same examiners, and the average of the 3 trials was used for statistical analysis. Previous studies reported the interobserver reliabilities of these measurements using intraclass correlation coefficients (ICCs).[15,18] They reported that interobserver reliabilities for external rotation and internal rotation were 0.73 and 0.89, respectively.[15] In this study, we assessed the intraobserver reliability of measurement using all ROM measures.

The rotation angle of the proximal humerus relative to that of the distal humerus (humeral torsion angle) was bilaterally measured using ultrasonography, as previously described (Fig. 2).[15,18] Players were placed in the supine position with the shoulder at 90° of abduction, the elbow at 90° flexion, and the forearm in the neutral position. The humeral torsion angle was defined as the angle between the long axis of the forearm and a line parallel to the trunk when the line tangential to the greater tuberosity and lesser tuberosity (forming the bicipital groove) was parallel to the horizontal baseline on the ultrasound monitor, while the ultrasound probe was held parallel to the floor. The humeral torsion angle was similarly measured using a digital inclinometer (accuracy, 0.1°, Smart Tool; M-D Building Products) that was placed on the palmar side of the forearm. In this study, a greater numerical value implied greater humeral torsion and greater humeral retroversion. The measurements of the humeral torsion angle were bilaterally taken twice by the same examiners, and the average of the 2 trials was used for statistical analysis. Previous studies demonstrated that the ICCs of this measurement for humeral retroversion were 0.89 for interobserver reliability.[15,18] In this study, we assessed the intraobserver reliability using all humeral torsion angle measures.

Statistical analyses

We calculated ICCs in the assessment of the intraobserver reliability of measurements. Subsequently, in the examination of the absolute reliability and the degree to which repeated measurements vary for individuals, the standard error of measurement (SEM) was calculated as SD $\times\sqrt{1 - \text{ICC}}$. The SEM was used for calculating the minimal detectable change (MDC_{90}), which was calculated as SEM $\times$ 1.65 $\times$ $\sqrt{2}$. Data were expressed as mean ± standard deviation. The mean humeral torsion angle was compared between the dominant and

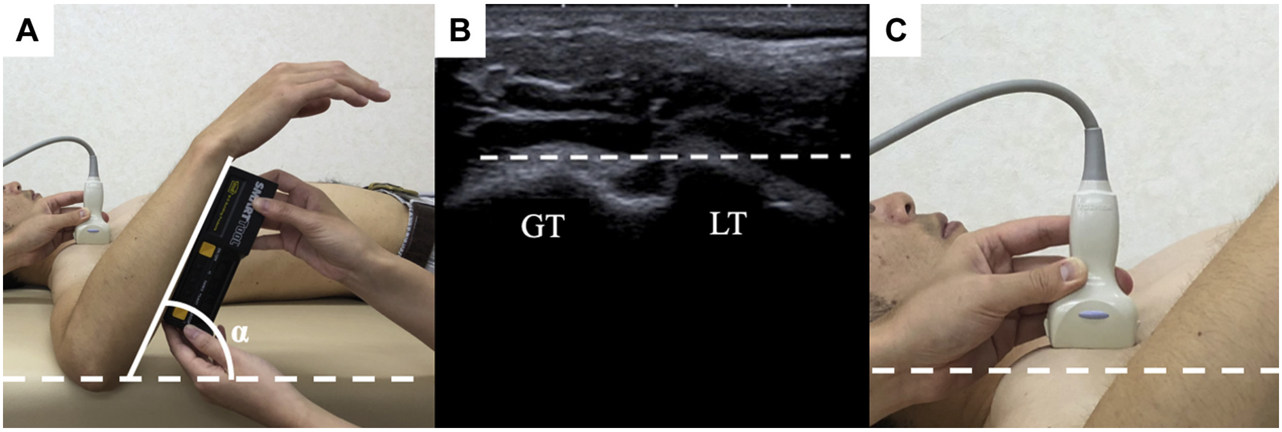

Figure 2 The humeral torsion angle was measured using ultrasonography, as previously described.[15,18] Players were placed in the supine position with the shoulder at 90° of abduction, the elbow at 90° flexion, and the forearm in the neutral position. (**A**) The humeral torsion angle was defined as the angle (α) between the long axis of the forearm and a line parallel to the trunk, (**B**) when the line tangential to the greater tuberosity (GT) and lesser tuberosity (LT, forming the bicipital groove) was parallel to the horizontal baseline on the ultrasound monitor, (**C**) while the ultrasound probe was held parallel to the floor. The humeral torsion angle (α) was measured using a digital inclinometer (Smart Tool, M-D Building Products; accuracy, 0.1°) placed on the palmar side of the forearm.

nondominant shoulders using the paired *t* test. For the comparison among the 3 groups, a one-way analysis of variance followed by Tukey post hoc test was used. Pearson correlation coefficient was used to analyze the relationship between the humeral retroversion and length of entire baseball career or career as a pitcher. The correlation coefficient (*r* value) was interpreted according to commonly used definitions as follows: <0.1, negligible; 0.10-0.39, weak; 0.40-0.69, moderate; 0.70-0.89, strong, and >0.9, very strong relationship.[1,27] The associations between humeral torsion angle and studied variables (the prevalence of pain during the medical checkup or self-reported history of injuries in the dominant shoulder or elbow) were determined by calculating the odds ratios (ORs), with 95% confidence intervals (CIs), using logistic regression analyses. Values of $P < .05$ were considered statistically significant. All statistical analyses were performed using the JMP Pro 14.0 software (SAS Institute Inc., Cary, NC, USA).

We used the G*Power3 package to perform a power analysis after data collection. We calculated the power (1 − β) of comparison among the 3 groups by defining the sample size as 34 (for group 1), 48 (for group 2), and 67 (for group 3), the threshold of significance (α) as 0.05, and the effect size as 0.23 for humeral retroversion in the dominant shoulder. Similarly, we calculated the power (1 − β) of comparison between the dominant shoulder and nondominant shoulder in each group by defining the sample size as 34 (for group 1), 48 (for group 2), 67 (for group 3), and 149 (in total), and threshold of significance (α) as 0.05. In addition, the effect size was defined as 1.07 (for group 1), 0.97 (for group 2), 0.81, (for group 3), and 0.84 (in total), respectively, for humeral retroversion; 0.92 (for group 1), 0.80 (for group 2), 0.94 (for group 3), and 0.89 (in total), respectively, for external rotation; 1.48 (for group 1), 1.57 (for group 2), 1.57 (for group 3), and 1.54 (in total), respectively for internal rotation; and 0.67 (for group 1), 0.78 (for group 2), 0.80 (for group 3), and 0.76 (in total), respectively, for total arc of rotation.

Results

In the power analysis, the comparison among the 3 groups demonstrated a power of 0.70 for the humeral torsion angle in the dominant shoulder. The comparison between the dominant and nondominant shoulders revealed power ranging between 0.99-1.0 for humeral torsion angle, 0.99-1.0 for external rotation, 0.99-1.0 for internal rotation, and 0.97-1.0 for the total arc of rotation.

The ICC for the shoulder ROM measurement was 0.94 for external rotation and 0.94 for internal rotation. Values of SEM were 2.4° for external rotation and 3.0° for internal rotation. In addition, values of MDC_{90} were 5.6° for external rotation and 7.1° for internal rotation. The ICC for measurement of humeral torsion angle was 0.96; the values of SEM and MDC_{90} were 2.5° and 5.9°, respectively.

The average age during medical checkup and the age when subjects started playing baseball did not differ significantly among the 3 groups (Table I). In all groups, humeral torsion angle was significantly greater in the dominant shoulder than in the nondominant shoulder ($P < .001$) (Table II). In particular, humeral torsion angle was greater in group 1 (96.2° ± 13.8°) than in group 3 (89.4° ± 11.7°) ($P = .02$). For all players, the mean side-to-side difference in humeral torsion angle was 9.8° ± 10.7° and was observed to be higher in group 1 (13.0° ± 12.2°) than in group 3 (8.1° ± 9.9°); however, the difference was not significant ($P = .09$). In all groups, the maximum external rotation was significantly greater in the dominant shoulder than in the nondominant shoulder ($P < .001$ in all groups), whereas the maximum internal rotation and total arc of rotation were significantly less ($P < .001$ in all groups). External rotation, internal

Table II Humeral torsion angle and shoulder ROM according to the positions played in the elementary school and junior-high school

	Group 1 (pitcher) (n=34)	Group 2 (pitcher/fielder) (n = 48)	Group 3 (fielder) (n = 67)	Total (n = 149)
Humeral torsion angle (°)				
Dominant side	96.2 ± 13.8*,†	91.8 ± 11.3*	89.4 ± 11.7*	91.7 ± 12.3*
Nondominant side	83.2 ± 12.5	81.7 ± 11.6	81.3 ± 9.6	81.9 ± 10.9
Side-to-side difference	13.0 ± 12.2	10.0 ± 10.3	8.1 ± 9.9	9.8 ± 10.7
External rotation (°)				
Dominant side	113.9 ± 7.9*	113.5 ± 9.6*	110.1 ± 10.3*	112.1 ± 9.7*
Nondominant side	105.5 ± 10.2	106.4 ± 5.6	103.0 ± 8.5	104.7 ± 8.2
Side-to-side difference	8.3 ± 8.9	7.1 ± 8.9	7.6 ± 7.6	7.4 ± 8.3
Internal rotation (°)				
Dominant side	28.4 ± 13.6‡	25.3 ± 12.3‡	27.6 ± 11.9‡	27.1 ± 12.4‡
Nondominant side	43.9 ± 10.2	42.5 ± 10.5	42.7 ± 11.8	42.9 ± 11.0
Side-to-side difference	−15.5 ± 10.4	−17.1 ± 10.9	−15.1± 9.6	−15.9 ± 10.2
Total arc of rotation (°)				
Dominant side	142.3 ± 15.3‡	138.8 ± 16.8‡	137.7 ± 16.6‡	139.1 ± 16.4‡
Nondominant side	149.4 ± 13.9	148.9 ± 12.9	145.7 ± 14.1	147.6 ± 13.7
Side-to-side difference	−7.1 ± 10.6	−10.1 ± 13.0	−7.9 ± 9.9	−8.5 ± 11.1

ROM, range of motion.
Data are expressed as mean ± standard deviation.
* Significantly greater ($P < .001$) than value for the nondominant side.
† Significantly greater ($P = .02$) than value for the dominant side of subjects in group 3.
‡ Significantly less ($P < .001$) than value for the nondominant side.

rotation, and the total arc of rotation in the dominant or nondominant shoulder did not significantly differ among the 3 groups.

Subsequently, we assessed the correlations between humeral torsion angle and the length of career as a pitcher or that of entire baseball career during elementary school and junior-high school. A positive correlation was observed between the humeral torsion angle and the length of career as a pitcher in the dominant shoulder ($P = .005$, $r = 0.23$); however, no positive correlation was observed in the nondominant shoulder ($P = .21$, $r = 0.10$). On the contrary, no significant correlation was noted between the humeral torsion angle and the length of total baseball career in the dominant shoulder ($P = .34$, $r = 0.08$) and the nondominant shoulder ($P = .80$, $r = 0.02$) (Table III).

The association between humeral torsion angle and the prevalence of pain during the medical checkup and self-reported history of injuries in the dominant shoulder or elbow were consequently assessed according to ORs, 95% CIs, and *P* values (Table IV). Of 149 study subjects in total, 12 players had shoulder pain and 25 players had elbow pain during the medical checkup. In addition, 60 players had self-reported history of shoulder injury, whereas 92 players had that of elbow injuries. Forty players had no self-reported history of shoulder or elbow injury. Humeral torsion angle was not correlated with the prevalence of pain during the medical checkup or a self-reported history of injuries in the dominant shoulder or elbow (*P* values ranging from .09-.99).

Table III The correlation between the humeral torsion angle and length of career as a pitcher or entire baseball career

	r values	*P* values
Length of career as pitchers		
Dominant	0.23	**.005***
Nondominant	0.10	.21
Length of entire baseball career		
Dominant	0.08	.34
Nondominant	0.02	.80

* Significant correlation between the humeral torsion angle in the dominant shoulder and length of career as a pitcher ($P = .005$).

Discussion

The most important finding of this study was that humeral retroversion was significantly greater in baseball players who were pitchers in both elementary school and junior-high school than in players who were fielders during both periods even though the age when they started playing baseball did not differ. Furthermore, we found a significant positive correlation between the length of career as a pitcher during elementary school and junior-high school, and humeral retroversion in the dominant shoulder although the value of correlation coefficient ($r = 0.23$) was interpreted as weak correlation according to previous definitions.[1,27] Notably, this correlation was not observed in the

Table IV Association between humeral torsion angle and prevalence of pain during the medical checkup or history of shoulder or elbow injuries

	Number (%)	Dominant side			Nondominant side			Side-to-side difference		
		Odds ratio	95% CI	*P* values	Odds ratio	95% CI	*P* values	Odds ratio	95% CI	*P* values
Prevalence of shoulder pain	12 (8.1)	1.00	0.95, 1.05	.99	1.00	0.95, 1.06	.88	1.00	0.94, 1.05	.87
Prevalence of elbow pain	25 (16.8)	0.99	0.95, 1.02	.50	1.04	0.99, 1.08	.10	0.97	0.93, 1.01	.17
History of shoulder injury	60 (40.3)	1.00	0.98, 1.03	.83	1.01	0.98, 1.05	.32	0.98	0.95, 1.01	.21
History of elbow injury	92 (61.7)	0.99	0.96, 1.02	.52	1.01	0.98, 1.04	.35	1.00	0.97, 1.02	.83
No history of shoulder or elbow injury	40 (26.8)	0.99	0.96, 1.02	.71	0.97	0.94, 1.00	.09	1.02	0.97, 1.05	.18

CI, confidence interval.

nondominant shoulder. On the contrary, no significant correlation was noted between the length of entire baseball career and humeral retroversion in either the dominant or the nondominant shoulder. These results suggest that playing baseball as a pitcher during elementary school and junior-high school affects the increases in the humeral retroversion in the dominant shoulder. Because pitchers throw more frequently than fielders during baseball games,[3] and are thought to experience greater torsional stress on their throwing limb than fielders,[26] increasing the frequency of pitching during elementary school and junior-high school may increase humeral retroversion in the dominant shoulder.

On the other hand, the humeral retroversion of baseball players who were fielders in both elementary school and junior-high school was significantly greater in the dominant shoulder than the nondominant shoulder. This suggests that playing baseball in elementary school and junior-high school (even as fielders only) increases humeral retroversion. This result was consistent with findings from previous reports.[15,28]

Humeral retroversion in baseball players has been assumed to occur around the proximal physis.[21,24,25] The epiphyseal plate consists of the fibrous, cartilaginous, and bony parts. The cartilage of the epiphyseal plate is weaker than the surrounding ligaments and is susceptible to torsional stress.[4,8] The shear stress arising from high torques during the arm cocking throwing phase in overhead sports is significant enough to lead to the deformation of the weak proximal humeral epiphyseal cartilage.[25] In the pediatric population, the closure of the growth plate of the proximal humerus starts around 14 years of age, and the last anatomic site to close is the posterolateral region, which closes at 17 years of age.[14] Little Leaguer's shoulder, a proximal humeral epiphysiolysis, is known to occur as a result of excessive rotational stress on the proximal physis during throwing motion in preadolescent or adolescent throwing athletes.[11,25] In addition, Johanson et al[12] found alterations in the lateral and ventral growth plates of the proximal humerus in the dominant arm of asymptomatic elite adolescent tennis players; this implies that repetitive loading in the overhead motion during elementary and junior-high schools may increase the humeral retroversion around the proximal epiphyseal plate without causing throwing injuries. Recently, a 3-dimensional computed tomographic analysis showed that side-to-side differences in humeral retroversion were observed at the insertions of the internal rotators of the pectoralis major, latissimus dorsi, and teres major, as well as around the proximal epiphyseal plate in baseball players between the age of 15-38 years.[10] A previous electromyographic study showed that the internal rotator muscles of the humerus (subscapularis, pectoralis major, and latissimus dorsi) become extremely active and contract eccentrically during late cocking, with their activity progressing into the acceleration phase of the throwing motion.[9] Repetitive throwing and pitching in elementary and junior-high schools could similarly increase the tensile stress at the insertions of internal rotator muscles; this, therefore, restricts the physiological derotation of the humerus during growth and increasing humeral retroversion, compared to that of the nondominant humerus in baseball players.

Several studies have demonstrated that the increased humeral retroversion in baseball players is an adaptation to prevent throwing-related injuries in the shoulder joint.[6,15,19,23] Increased humeral retroversion in throwing athletes is thought to increase external rotation and decrease internal rotation of the shoulder joint due to the shift of the rotational arc.[6,15,24] Increased external rotation is thought to produce greater ball speed and, thus, allows athletes to play at a higher competitive level.[30] Furthermore, increased humeral retroversion in the throwing arm allows pitchers to achieve maximum external rotation with less twisting and traction on the anterior capsules, long head of the biceps, and rotator cuff tendons.[23]

In contrast, some previous studies reported that college[17] and professional baseball pitchers with a history of elbow injuries, such as ulnar collateral ligament injury, demonstrated a greater side-to-side difference in humeral retroversion.[19] In addition, Ito et al[11] has reported that high school baseball players with severely increased humeral retroversion following an incidence of Little Leaguer's shoulder demonstrated a high rate of shoulder or elbow injury. The mean side-to-side difference in humeral retroversion in players with shoulder or elbow injuries ranged from 20.0°-23.2° in previous studies.[11,17,19] In this study, however, no correlation was observed between humeral retroversion and the prevalence of pain during the medical checkup or self-reported history of injuries in the dominant shoulder or elbow. In this cohort, the mean side-to-side difference in humeral retroversion was 9.8°, which was consistent with the values of asymptomatic high school baseball players or those with no throwing injuries in previous studies (range, 8.3-13.4).[11,15,22] These results suggest that increased humeral retroversion of the dominant shoulder due to repetitive throwing motion during elementary and junior-high schools is an adaptive change, rather than a pathologic change. However, excessive humeral retroversion, which may occur after throwing-related pathologies, such as Little Leaguer's shoulder, may increase the risk of throwing injuries in baseball players.

This study has some limitations. First, we did not investigate the pitching volume and characteristics (pitch counts, innings pitched, velocity, and competitive level) during elementary and junior-high schools, with potential effects on the humeral retroversion. However, it is known that pitchers throw more frequently than fielders.[3] Therefore, we believe that the increased frequency of throwing contributed to the differences between players who were pitchers in elementary and junior-high schools and those who were not. Second, we did not investigate the effects of baseball positions played during high-school. However, Oyama et al[21] reported that the humeral retroversion did not change over a year in a cohort of 138 high-school baseball players. Furthermore, we included only baseball players in the first year of high school to minimize the effects of position played in high school. Thus, we believe the position played in high school does not affect the results of our study. Third, we used self-reported data in the analysis of the correlation between humeral retroversion and history of shoulder or elbow injuries; therefore, there is a possibility of recall bias, although we asked all participants to complete the questionnaires with the cooperation of their family. Fourth, throwing injuries due to increased humeral torsion might be observed later in the playing career. Therefore, further longitudinal study is needed to investigate the correlation between the humeral torsion and shoulder and elbow injuries in baseball players. Fifth, likely errors could have been overlooked due to differences in muscle mass between sides because the inclinometer was aligned with the forearm.

To our knowledge, this is the first study to demonstrate that baseball positions played in elementary and junior-high schools affect the humeral retroversion. In the future, longitudinal analysis of humeral retroversion that incorporates more precise measures of participation volume, pitch counts, and innings pitched during elementary and junior-high schools will provide further knowledge regarding changes in the humeral retroversion in baseball players.

Conclusions

High-school baseball players who were pitchers in both elementary school and junior-high school had greater humeral retroversion in the dominant side than those who were fielders during both periods. Humeral retroversion in the dominant shoulder was positively correlated with the length of career as a pitcher during elementary school and junior-high school. These results suggest that playing baseball as a pitcher during elementary school and junior-high school affects the increase in humeral retroversion in the dominant shoulder. Moreover, the increased humeral retroversion in the dominant shoulder was not correlated with shoulder and elbow pain in this study. This result suggests that the increased humeral retroversion in the dominant shoulder by repetitive throwing motion during elementary and junior-high schools is an adaptive change, rather than a pathologic change.

Disclaimer

The authors, their immediate families, and any research foundations 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.

Acknowledgments

The authors thank C.Watanabe, K. Fukunishi, K. Yasui, T. Kawakami, and Y. Fujisawa from the Department of Orthopaedic Surgery, Osaka Medical College (Takatsuki, Japan), K. Makino, K. Takaya, C. Nakase, and A. Kamii from Department of Rehabilitation, First Towakai Hospital (Takatsuki, Japan) for participating in the medical checkup. We also thank Keisuke Fukui for his assistance with statistical analysis.

References

1. Akoglu H. User's guide to correlation coefficients. Turk J Emerg Med 2018;18:91-3. https://doi.org/10.1016/j.tjem.2018.08.001

2. American Academy of Orthopaedic Surgeons. Joint motion: method of measuring and recording. Chicago, IL: American Academy of Orthopaedic Surgeons; 1965.
3. Barrett DD, Burton AW. Throwing patterns used by collegiate baseball players in actual games. Res Q Exerc Sport 2002;73:19-27. https://doi.org/10.1080/02701367.2002.10608988
4. Caine D, DiFiori J, Maffulli N. Physeal injuries in children's and youth sports: reasons for concern? Br J Sports Med 2006;40:749-60. https://doi.org/10.1136/bjsm.2005.017822
5. Cowgill LW. Humeral torsion revisited: a functional and ontogenetic model for populational variation. Am J Phys Anthropol 2007;134:472-80. https://doi.org/10.1002/ajpa.20689
6. Crockett HC, Gross LB, Wilk KE, Schwartz ML, Reed J, O'Mara J, et al. Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. Am J Sports Med 2002;30:20-6. https://doi.org/10.1177/03635465020300011701
7. Edelson G. The development of humeral head retroversion. J Shoulder Elbow Surg 2000;9:316-8.
8. Gill TJt, Micheli LJ. The immature athlete. Common injuries and overuse syndromes of the elbow and wrist. Clin Sports Med 1996;15:401-23.
9. Glousman R, Jobe F, Tibone J, Moynes D, Antonelli D, Perry J. Dynamic electromyographic analysis of the throwing shoulder with glenohumeral instability. J Bone Joint Surg Am 1988;70:220-6.
10. Itami Y, Mihata T, Shibano K, Sugamoto K, Neo M. Site and severity of the increased humeral retroversion in symptomatic baseball players: a 3-dimensional computed tomographic analysis. Am J Sports Med 2016;44:1825-31. https://doi.org/10.1177/0363546516638331
11. Ito A, Mihata T, Hosokawa Y, Hasegawa A, Neo M, Doi M. Humeral retroversion and injury risk after proximal humeral epiphysiolysis (Little Leaguer's shoulder). Am J Sports Med 2019;47:3100-6. https://doi.org/10.1177/0363546519876060
12. Johansson FR, Skillgate E, Adolfsson A, Jenner G, De Bri E, Sward L, et al. Asymptomatic elite young tennis players show lateral and ventral growth plate alterations of proximal humerus on MRI. Knee Surg Sports Traumatol Arthrosc 2017;25:3251-9. https://doi.org/10.1007/s00167-016-4024-2
13. Kurokawa D, Yamamoto N, Ishikawa H, Nagamoto H, Takahashi H, Muraki T, et al. Differences in humeral retroversion in dominant and non-dominant sides of young baseball players. J Shoulder Elbow Surg 2017;26:1083-7. https://doi.org/10.1016/j.jse.2016.11.051
14. Kwong S, Kothary S, Poncinelli LL. Skeletal development of the proximal humerus in the pediatric population: MRI features. AJR Am J Roentgenol 2014;202:418-25. https://doi.org/10.2214/AJR.13.10711
15. Mihata T, Takeda A, Kawakami T, Itami Y, Watanabe C, Doi M, et al. Isolated glenohumeral range of motion, excluding side-to-side difference in humeral retroversion, in asymptomatic high-school baseball players. Knee Surg Sports Traumatol Arthrosc 2016;24:1911-7. https://doi.org/10.1007/s00167-014-3193-0
16. 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/10.1177/0363546512436801
17. Myers JB, Oyama S, Rucinski TJ, Creighton RA. Humeral retrotorsion in collegiate baseball pitchers with throwing-related upper extremity injury history. Sports Health 2011;3:383-9. https://doi.org/10.1177/1941738111410636
18. Nakase C, Mihata T, Itami Y, Takeda A, Neo M. Relationship between humeral retroversion and length of baseball career before the age of 16 years. Am J Sports Med 2016;44:2220-4. https://doi.org/10.1177/0363546516651864
19. Noonan TJ, Thigpen CA, Bailey LB, Wyland DJ, Kissenberth M, Hawkins RJ, et al. Humeral torsion as a risk factor for shoulder and elbow injury in professional baseball pitchers. Am J Sports Med 2016;44:2214-9. https://doi.org/10.1177/0363546516648438
20. Osbahr DC, Cannon DL, Speer KP. Retroversion of the humerus in the throwing shoulder of college baseball pitchers. Am J Sports Med 2002;30:347-53. https://doi.org/10.1177/03635465020300030801
21. Oyama S, Hibberd EE, Myers JB. Changes in humeral torsion and shoulder rotation range of motion in high school baseball players over a 1-year period. Clin Biomech (Bristol, Avon) 2013;28:268-72. https://doi.org/10.1016/j.clinbiomech.2013.01.014
22. Oyama S, Hibberd EE, Myers JB. Preseason screening of shoulder range of motion and humeral retrotorsion does not predict injury in high school baseball players. J Shoulder Elbow Surg 2017;26:1182-9. https://doi.org/10.1016/j.jse.2017.03.038
23. Polster JM, Bullen J, Obuchowski NA, Bryan JA, Soloff L, Schickendantz MS. Relationship between humeral torsion and injury in professional baseball pitchers. Am J Sports Med 2013;41:2015-21. https://doi.org/10.1177/0363546513493249
24. Reagan KM, Meister K, Horodyski MB, Werner DW, Carruthers C, Wilk K. Humeral retroversion and its relationship to glenohumeral rotation in the shoulder of college baseball players. Am J Sports Med 2002;30:354-60. https://doi.org/10.1177/03635465020300030901
25. Sabick MB, Kim YK, Torry MR, Keirns MA, Hawkins RJ. Biomechanics of the shoulder in youth baseball pitchers: implications for the development of proximal humeral epiphysiolysis and humeral retrotorsion. Am J Sports Med 2005;33:1716-22. https://doi.org/10.1177/0363546505275347
26. Sabick MB, Torry MR, Kim YK, Hawkins RJ. Humeral torque in professional baseball pitchers. Am J Sports Med 2004;32:892-8. https://doi.org/10.1177/0363546503259354
27. Schober P, Boer C, Schwarte LA. Correlation coefficients: appropriate use and interpretation. Anesth Analg 2018;126:1763-8. https://doi.org/10.1213/ANE.0000000000002864
28. Takenaga T, Goto H, Tsuchiya A, Yoshida M, Fukuyoshi M, Nakagawa H, et al. Relationship between bilateral humeral retroversion angle and starting baseball age in skeletally mature baseball players-existence of watershed age. J Shoulder Elbow Surg 2019;28:847-53. https://doi.org/10.1016/j.jse.2018.10.017
29. Takenaga T, Sugimoto K, Goto H, Nozaki M, Fukuyoshi M, Tsuchiya A, et al. Posterior shoulder capsules are thicker and stiffer in the throwing shoulders of healthy college baseball players: a quantitative assessment using shear-wave ultrasound elastography. Am J Sports Med 2015;43:2935-42. https://doi.org/10.1177/0363546515608476
30. Werner SL, Suri M, Guido JA Jr, Meister K, Jones DG. Relationships between ball velocity and throwing mechanics in collegiate baseball pitchers. J Shoulder Elbow Surg 2008;17:905-8. https://doi.org/10.1016/j.jse.2008.04.002
31. Wyland DJ, Pill SG, Shanley E, Clark JC, Hawkins RJ, Noonan TJ, et al. Bony adaptation of the proximal humerus and glenoid correlate within the throwing shoulder of professional baseball pitchers. Am J Sports Med 2012;40:1858-62. https://doi.org/10.1177/0363546512452720
32. Yamamoto N, Itoi E, Minagawa H, Urayama M, Saito H, Seki N, et al. Why is the humeral retroversion of throwing athletes greater in dominant shoulders than in non-dominant shoulders? J Shoulder Elbow Surg 2006;15:571-5. https://doi.org/10.1016/j.jse.2005.06.009