

ORIGINAL ARTICLE

Relationship between the Lower Limb Function and Shoulder and Elbow Injuries in Elementary School Baseball Pitchers

Noritaka Hamano, MD, PhD Hitoshi Shitara, MD, PhD Tsuyoshi Tajika, MD, PhD
Tsuyoshi Ichinose, MD, PhD Tsuyoshi Sasaki, MD, PhD Takuro Kuboi, MD Daisuke Shimoyama, MD
Masataka Kamiyama, MD Ryosuke Miyamoto, MD Fumitaka Endo, MD Kurumi Nakase, MD
Tsutomu Kobayashi, MD, PhD Atsushi Yamamoto, MD, PhD Kenji Takagishi, MD, PhD
and Hirotaka Chikuda, MD, PhD

Objectives: We aimed to examine the relationship between the hip range of motion (ROM) and ankle ROM and throwing-related shoulder and elbow injuries in elementary school baseball pitchers. **Methods:** This retrospective comparative study (Level of evidence: Level III) included 195 baseball pitchers (mean age 10.8±1.0 years, range 8–12 years). All pitchers underwent physical function measurements, including height, weight, shoulder strength, and hip and ankle ROM. Shoulder and elbow injury was defined as shoulder and elbow pain that the pitchers had been aware of in the past or at the time of medical checkups. The results for the injured and non-injured groups were then compared. **Results:** The shoulder ROM and strength in the injured and non-injured groups did not differ to a statistically significant extent. The hip external rotation on the dominant side (injured vs. non-injured: 48.9±11.1° vs. 53.3±9.7°, P<0.01), the hip internal rotation on the non-dominant side (injured vs. non-injured: 36.6±12.0° vs. 40.9±11.0°, P=0.01), and ankle plantar flexion on the non-dominant side (injured vs. non-injured: 52.0±6.8° vs. 54.3±6.7°, P=0.02) were significantly smaller in the injured group than in the non-injured group. **Conclusions:** The hip external rotation ROM on the dominant side and the hip internal rotation and ankle plantar flexion on the non-dominant side were significantly lower in the injured group than in the non-injured group. These results may suggest measures to reduce the incidence of elbow and shoulder injuries in elementary school baseball pitchers.

Key Words: baseball; elementary school; hip joint; medical checkups; pitcher

INTRODUCTION

Although several risk factors for shoulder and elbow injuries have been elucidated, shoulder and elbow injuries in young baseball players remain a major problem.¹⁾ A previous study reported that the overall incidence of elbow pain in elementary school baseball players was 1.5 per 1000 athlete exposures (AEs), and the overall incidence of shoulder pain was 0.6 per 1000 AEs.²⁾ In the same study, it was also reported that the incidence of elbow pain in elementary school

baseball pitchers was 2.5 per 1000 AEs, and the rate of medial elbow injuries was 2.2 per 1000 AEs.²⁾ Although many studies have been conducted on the upper limb, few studies have so far been conducted on the lower limb. For example, previous studies have reported that glenohumeral internal rotation deficit, shoulder external rotation insufficiency,³⁾ high pitch velocity,⁴⁾ deficits in preseason supraspinatus, prone external rotation strength,⁵⁾ and imbalance of muscle strength around the shoulder⁶⁾ were risk factors for shoulder and elbow inju-

Received: October 19, 2020, Accepted: February 3, 2021, Published online: March 10, 2021

Department of Orthopaedic Surgery, Gunma University Graduate School of Medicine, Maebashi, Japan

Correspondence: Hitoshi Shitara, MD, PhD, Department of Orthopaedic Surgery, Gunma University Graduate School of Medicine, 3-39-22 Showamachi, Maebashi, Gunma 371-8511, Japan, E-mail: hshitara@gunma-u.ac.jp

Copyright © 2021 The Japanese Association of Rehabilitation Medicine



This is an open-access article distributed under the terms of the Creative Commons Attribution Non-Commercial No Derivatives (CC BY-NC-ND) 4.0 License. <http://creativecommons.org/licenses/by-nc-nd/4.0/>

ries. Furthermore, a recent systematic review regarding research on pitching mechanics in youth baseball players also focused on the upper extremities.⁷⁾ The absence of research on the relevance of the lower extremities in throwing-related upper extremity injuries is problematic because the biomechanics of the lower extremities are a fundamental part of the throwing motion. This is because the tremendous energy generated by the lower extremities is transferred through the kinetic chain ultimately to the ball through the trunk, shoulder, elbow, and hand.⁸⁾ A young pitcher with poor lower body mechanics often tries to compensate for such deficiencies, thereby putting stress on the upper limb and increasing the risk of injury.⁷⁾ The number of studies investigating dysfunction of the trunk and lower extremities as risk factors for shoulder and elbow injuries is relatively small in comparison to those investigating the risk factors related to the upper extremities. Significant associations have been demonstrated between throwing-related shoulder and elbow injuries and trunk and lower limb dysfunction,⁹⁾ abnormal foot posture,¹⁰⁾ and hip range of motion (ROM) deficits in elementary school baseball players.^{2,11,12)} Furthermore, no study has so far addressed the relationship between hip and ankle ROM and shoulder and elbow injuries in elementary school baseball players, or specifically pitchers. Consequently, the purpose of this study was to investigate the relationship between hip and ankle ROM and the incidence of shoulder and elbow injuries with a focus on elementary school baseball pitchers.

In this study, we evaluated the hypothesis that a restricted ROM in the hip and ankle of pitchers is related to shoulder or elbow injuries.

MATERIALS AND METHODS

Participants

A total of 463 elementary and junior high school baseball players belonging to the Gunma Prefecture Elementary and Junior High School Baseball Federation who participated in medical checkups held at Gunma University Hospital in February 2016 were enrolled. Before enrolment in the study, all players and their parents provided written informed consent. The study was approved by the Institutional Review Board of Gunma University Hospital on January 28, 2015 (Identification number 1003 2015–01-28). All methods were carried out in accordance with the relevant guidelines and regulations. Being able to collect a questionnaire to be filled in at the time of participation in the medical checkups and the provision of informed consent by both the player and their parents were among the inclusion criteria. Junior high

school students were excluded from this study because of the difference in body size between junior high school and elementary school students. Furthermore, we specifically targeted pitchers, even among elementary school baseball players. As a result, players who only played in the field were excluded (**Fig. 1**).

Medical Checkups

We asked the players to fill out a questionnaire at the checkups; the questionnaire included the player's age and dominant arm. All pitchers underwent measurements of their physical function, such as height, weight, shoulder strength and ROM, and hip and ankle ROM. To avoid any confirmation bias, the examiners were blinded to the participants' hand dominance. ROM measurements were performed before muscle strength measurements because muscle tonus can vary with the effects of reciprocal inhibition due to muscle contraction.

Shoulder and Elbow ROM

The ROMs were measured with the subject in the supine position. We previously established the intra-rater validity and reliability of the goniometer and hand-held dynamometers.^{6,13)} Following the methodology of previous studies,⁶⁾ certified orthopedic surgeons measured the bilateral passive elbow ROM of flexion and extension, the passive shoulder ROM of horizontal adduction, and 90°-abducted external and internal rotation using a digital protractor (iGaging, San Clemente, CA, USA). When measuring passive horizontal adduction, the examiner stabilized the axillary border of the scapula and another certified orthopedic surgeon placed a digital protractor on the humerus. When measuring the passive external rotation and internal rotation, the examiner stabilized the scapula by applying a posterior force to the coracoid process and another certified orthopedic surgeon placed a digital protractor on the forearm. Elbow flexion and extension ROMs were also passively measured with the participants in a supine position.

Shoulder Strength

A single certified orthopedic surgeon performed strength measurements in an isometric manner according to a specific protocol. Muscle strength measurements were performed in a manner similar to that reported by Byram *et al*.⁵⁾ As in previous studies,^{5,6,14)} certified orthopedic surgeons measured the internal and external rotation strength in both shoulders using a PowerTrack II Commander hand-held dynamometer (J-Tech Medical, Salt Lake City, UT, USA). The intra-rater validity and reliability of shoulder strength measurements

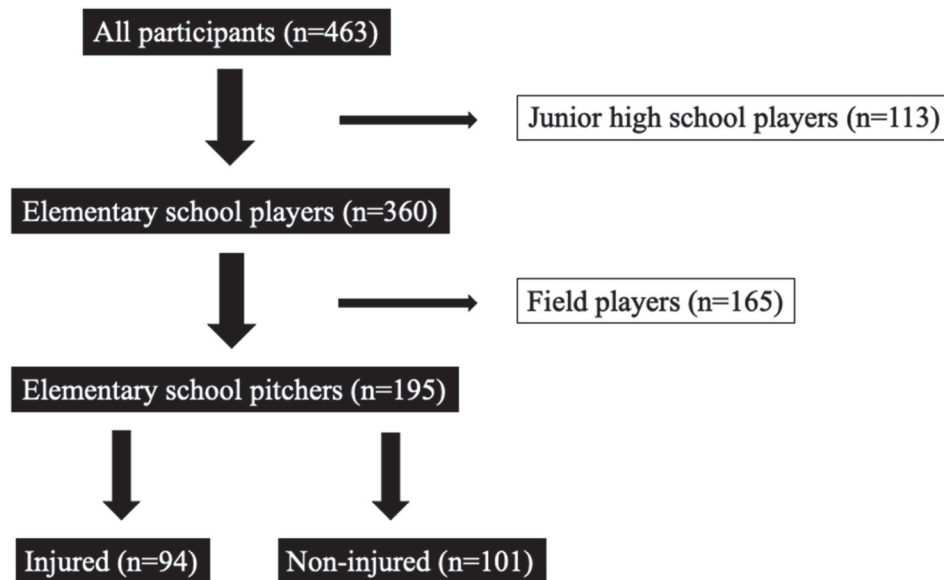


Fig. 1. Flow chart of the pitchers included in this study.

by hand-held dynamometers were established in a previous study.⁶⁾ In the present study, the intra- and/or inter-rater reliability of all measurements of shoulder strength were established in ten healthy volunteers.⁶⁾ The intraclass correlation coefficients (ICCs) of intra-rater measures were in the acceptable range for external and internal rotation strength [ICC_(1,2)=0.96 and 0.98; 95% confidence interval (CI) 0.83–0.99 and 0.93–0.99, respectively].⁶⁾ Internal and external rotation were measured with abduction of the humerus to 90° and 90° of elbow flexion. Next, the examiner stabilized the humerus, and the arm was set in a neutral position. The participant was then asked to rotate their arm externally or internally with maximum power against the dynamometer. When measuring internal and external rotation, the dynamometer was placed on the volar and dorsal sides of the forearm respectively, 5 cm proximal to the proximal wrist flexion crease. Three trials were performed for each muscle strength measurement, and the median value of the three trials was recorded and used for the analysis.

Hip and Ankle ROM

All hip ROM data were collected by two orthopedic surgeons using a digital protractor (iGaging) and utilizing a reliable and previously validated technique.^{15,16)} With one of the measurers immobilizing the athlete's pelvis in the prone position, the other measurer bent the knee on the measurement side 90° and rotated the hip joint internally and externally with 0° of flexion. The other leg was kept straight on

the ground. The angles between the perpendicular plane and the lower leg were defined as internal rotation and external rotation, respectively. The passive ankle dorsal and plantar flexion were measured with hip, knee, and ankle joints in a neutral position of flexion/extension and inversion/eversion in the supine position.¹⁷⁾ The participant's ankle and foot joints were passively dorsal or plantar flexed by the examiner. When measuring passive dorsal flexion, a digital protractor was aligned along the medial border of the tibia and the medial aspect of the foot. Whereas, when measuring passive plantar flexion, the digital protractor was aligned along the medial border of the tibia and the navicular bone.

Statistical Analyses

The baseline characteristics and the results of a univariate analysis were reported as the means ± standard deviations. In the questionnaire, “shoulder or elbow injury” was defined as the presence of any shoulder or elbow pain that the subject had been aware of since starting to play baseball (Appendix 1). In accordance with previous studies, shoulder injuries and elbow injuries were examined together.¹⁴⁾ The pitchers were divided into injured and non-injured groups according to the questionnaire replies. The results were analyzed using an independent *t*-test for continuous variables to compare the baseline characteristics between the groups. Thereafter, to identify the risk factors for shoulder and elbow injuries and to calculate odds ratios and 95% CIs, a logistic regression analysis was performed after adjusting for variables

Table 1. Demographic data for each group

	Non-injured (n=101)		Injured (n=94)		P value
	Mean	SD	Mean	SD	
Age (years)	10.6	1.1	10.9	1.3	0.05
Height (cm)	141.7	8.9	146.1	7.5	<0.01*
Weight (kg)	35.0	7.5	38.9	8.1	<0.01*

*Significant differences at P<0.05.

Table 2. Univariate analysis of the upper limb

	Non-injured (n= 101)		Injured (n=94)		P value
	Mean	SD	Mean	SD	
Shoulder on the dominant side					
Shoulder ER strength (kg)	8.1	2.0	8.4	2.1	0.53
Shoulder IR strength (kg)	8.9	2.6	8.8	2.5	0.50
Shoulder ER ROM (°)	114.4	10.1	115.7	10.2	0.35
Shoulder IR ROM (°)	46.1	18.1	42.7	12.4	0.75
Shoulder HA ROM (°)	106.6	12.7	105.7	13.0	0.60
Elbow on the dominant side					
Flexion ROM (°)	140.4	5.2	140.1	5.8	0.30
Extension ROM (°)	6.6	5.1	6.3	4.9	0.66

The shoulder ROM and strength in the injured and non-injured groups did not differ significantly. ER, external rotation; IR, internal rotation; HA, horizontal adduction.

that were identified as significant in the univariate analyses. Before performing logistic regression analysis, Pearson correlation coefficients were calculated to avoid multicollinearity. Variables that showed a P value of <0.1 on univariate analysis were included in the model. All statistical analyses were performed using the IBM SPSS Statistics software package (version 26, IBM Japan, Tokyo). P values of <0.05 were considered to indicate statistical significance.

RESULTS

Of the 387 players who visited for checkups, 113 junior high school students and 165 elementary school fielders were excluded; the remaining 195 elementary school pitchers were included in the study. Of the 195 pitchers (mean age 10.8±1.0, 8–12 years) who completed the questionnaire, 94 pitchers (48%) had either previously experienced or currently had shoulder or elbow injuries (**Fig. 1**).

Univariate Analysis

The height and weight of the injured group were significantly higher than those of the non-injured group (injured vs. non-injured: 146.1±7.5 cm vs. 141.7±8.9 cm, P<0.01, 38.9±8.1 kg vs. 35.0±7.5 kg, P<0.01, respectively) (**Table 1**). The

shoulder ROM and strength in the injured and non-injured groups did not differ to a statistically significant extent (**Table 2**). The hip external rotation on the dominant side (injured vs. non-injured: 48.9±11.1° vs. 53.3±9.7°, P<0.01), the hip internal rotation on the non-dominant side (injured vs. non-injured: 36.6±12.0° vs. 40.9±11.0°, P=0.01), and ankle plantar flexion on the non-dominant side (injured vs. non-injured: 52.0±6.8° vs. 54.3±6.7°, P=0.02) were significantly smaller in the injured group than in the non-injured group (**Table 3**).

Multivariate Analysis

Among the variables with P values less than 0.1 based on the results of univariate analyses, height and weight were significantly correlated with age (P<0.01, correlation coefficient=0.542 and 0.403, respectively). As a result, the height and weight data were removed. Logistic regression analysis showed that hip external rotation on the dominant side in the injured group was significantly smaller than that of the non-injured group (P=0.03, odds ratio 0.967) (**Table 4**).

Post-hoc Power Analysis

A post-hoc power analysis demonstrated the statistical power between the injured and non-injured groups to be 0.99.

Table 3. Univariate analysis of the lower limb

	Non-injured (n=101)		Injured (n=94)		P value
	Mean	SD	Mean	SD	
Hip on the non-dominant side					
IR ROM (°)	40.9	11.0	36.6	12.0	0.01*
ER ROM (°)	49.4	10.3	47.9	12.3	0.34
Hip on the dominant side					
IR ROM (°)	38.5	10.8	36.2	12.2	0.16
ER ROM (°)	53.3	9.7	48.9	11.1	<0.01*
Ankle on the non-dominant side					
PF ROM (°)	54.3	6.7	52.0	6.8	0.02*
DF ROM (°)	23.7	8.4	22.8	6.7	0.42
Ankle on the dominant side					
PF ROM (°)	53.6	7.5	52.0	9.7	0.18
DF ROM (°)	22.8	7.7	21.9	6.4	0.39

The hip external rotation on the dominant side, the hip internal rotation on the non-dominant side, and the ankle plantar flexion on the non-dominant side were significantly smaller in the injured group than in the non-injured group.

*Significant differences at $P < 0.05$.

PF, plantar flexion; DF, dorsal flexion.

Table 4. Results of the multivariate analysis

Variable	Odds ratio	95% CI	P value
Age	1.12	1.455–3.268	0.40
Ankle dorsal flexion (non-dominant)	0.959	0.900–0.995	0.07
Hip IR (non-dominant)	0.978	0.950–0.999	0.11
Hip ER (dominant)	0.967	0.939–0.996	0.03*

The hip external rotation on the dominant side was an independent predictor of shoulder and elbow injury in elementary school baseball pitchers.

*Significant difference at $P < 0.05$.

DISCUSSION

The important finding of this study was that a decreased hip ROM in external rotation on the dominant side was an independent risk factor of shoulder and elbow injuries in elementary school baseball pitchers. Furthermore, we found that the hip ROM in internal rotation and ankle plantar flexion on the non-dominant side, being tall, and being heavy were also associated with both shoulder and elbow injuries. To the best of our knowledge, this is the first study to provide evidence that hip and ankle ROM deficits can affect shoulder and elbow injuries in elementary school baseball pitchers.

Hip ROM Deficit

Recently, the concept of “the kinetic chain” has received a lot of attention, and there is growing evidence that any disruption in this chain of motion can affect subsequent elements, resulting in an increased risk of injuries.^{18,19} According to a

previous study, limitation of the hip joint internal ROM was one cause of disturbance of the kinetic chain.²⁰ Sakata et al. reported that the ROM of hip internal rotation on the non-dominant side was lower in players with elbow injuries than in players without elbow injuries in elementary and junior high school baseball players.²⁾ Sekiguchi et al. also noted that a small ROM of the hip internal rotation on the non-dominant side was associated with an awareness of shoulder and elbow injuries during competition in elementary school baseball players.¹²⁾ In the current study, we found similar results to those of Sekiguchi et al. The major difference between our study and theirs is the subject selection. The previous studies examined all players without dividing them into pitchers and fielders, which is a limitation in those studies. This is problematic because previous studies have shown that pitchers are susceptible to upper extremity injuries, as indicated by higher incidences of shoulder and elbow injuries.²¹⁾ Although no similar studies in the past have found shoulder and elbow

injuries to be associated with hip external rotation ROM, Crawford et al. measured the hip ROM required during the pitching motion and showed that internal rotation on the non-dominant side and external rotation on dominant side were specifically required.²²⁾ It has been found through pitching motion analyses that the non-dominant hip internal rotation ROM in particular is required during the early and late cocking phases, whereas throwing hip external rotation ROM is required only during the late cocking phase.²²⁾ The study of Crawford et al. was conducted on pitchers only, which could indirectly support the results of our study. This is because abnormal loading mechanics of the dominant limb and the landing pattern of the non-dominant limb during the pitching motion can result in inefficient energy transfer, thereby requiring the trunk and upper extremities to generate more force to maintain ball velocity.^{23,24)}

Ankle ROM Deficit

It is generally accepted that the pitching motion is divided into six phases: wind up, stride, arm cocking, acceleration, deceleration, and follow through.²⁵⁾ Although no previous report has investigated the association between ankle function and shoulder and elbow injuries, ankle function plays a critical role in the pitching motion. The ankle joint is involved in the early phase of the kinetic chain, and, consistent with the concept of the kinetic chain, improper positioning and movement of the ankle can affect all subsequent segments. Rabin et al. reported that a decreased ankle ROM is associated with increased frontal plane hip motion, increased transverse plane knee motion, and decreased sagittal plane knee motion.²⁶⁾ Therefore, changes in lower extremity kinematics during the early phases of the pitching motion could upset the latter phases.²⁷⁾ In the present study, univariate analysis demonstrated that the ROM of ankle plantar flexion on the non-dominant ankle in the injured group were significantly smaller than those in the non-injured group. Interestingly, whereas ankle dorsiflexion ROM limitation has been found to affect dynamic balance,²⁸⁾ no such ankle plantar flexion ROM limitation has been previously examined.

Although it is not possible to draw any definitive conclusions from the results of the current study as to why the group with limited plantar flexion of the ankle joint tended to have more shoulder and elbow injuries, in a previous study, during the stride phase, decreased maximum angular excursions for ankle plantar flexion were observed for each additional pitch count on the dominant side.²⁷⁾ That study also reported that improper positioning and movements of each joint can affect subsequent joint actions throughout the pitching motion.²⁷⁾

This fact may also explain why a limited ankle plantar ROM is associated with both shoulder and elbow injuries. However, there are additional factors for the ankle joint that need to be considered. For example, the throwing motion is performed while the lower limb is loaded, whereas assessment was performed in the non-loaded state, and the correlation between the loaded and non-loaded ankle ROM is only moderate.²⁹⁾ These facts suggest that these measurements may be assessing different constructs and may, therefore, yield different associations with the lower extremity kinematics. In the future, it will be necessary to measure the ROM of the ankle joint in the loaded state. Our findings suggest that a program to improve hip and ankle ROM may be useful for preventing the occurrence of shoulder and elbow injuries in elementary school baseball pitchers.

Demographics

Although age, height, and weight were not independent risk factors for shoulder and elbow injuries among elementary school baseball pitchers in this study, height and weight were associated with shoulder and elbow injuries according to the univariate analysis. Because age, height, and weight are strongly correlated, as evaluated by Pearson's correlation coefficients, these variables should therefore be discussed collectively. Takagishi et al. reported that the risk for arm injuries among pitchers increases with age, height, and weight.¹⁾ Lyman et al. also reported in their prospective study that age and weight were developmental risk factors for elbow injuries in 9- to 12-year-old baseball players.³⁰⁾ This finding is similar to the findings of our study, including the target age group. In addition, their hypothesis focused on the secondary ossification centers, which are the most vulnerable points in the young elbow, and these centers begin to ossify between 2 and 11 years of age and do not fuse to the long bones until as late as 17 years of age.³¹⁾ These developmental processes may explain why the rate of throwing-related elbow injuries increases with age.³¹⁾ Furthermore, heavier pitchers may place a greater load on their immature skeletons, thereby increasing the likelihood of developing elbow injuries. Taller pitchers are more likely to have longer arms, and longer arms are expected to weigh more than shorter arms, thereby resulting in more weight being maintained by the shoulder joint during pitching.³¹⁾ This creates a higher torque on the shoulder joint and could, therefore, be a source of shoulder injuries. Takagishi et al. reported that the number of years of baseball experience was not associated with the occurrence of shoulder pain in junior high school baseball players. This finding suggests that the load applied on the shoulders

increased as a player's physical abilities improved rather than being a chronic injury caused by continually playing the same sport and therefore correlated with older age. Evidently, a stronger degree of power means that a greater force is potentially applied to the shoulder and elbow. We must address additional factors in the future, while taking into account demographic factors such as age, height, and weight.

Limitations

The present study has some limitations. First, this was a cross-sectional study. Therefore, whether the decrease in the ROM of the hip joint was the cause or the result of shoulder and elbow injuries was unclear and might have been affected by recall bias. Second, we did not take into account the effects of trunk function, such as lumbar lordosis and dynamic balance. Third, we did not perform imaging tests, including radiography, computed tomography, or magnetic resonance imaging, to detect any pathological features in the participants' hip joints. Our study was based on medical checkups only; this was because we wanted to avoid unnecessary radiation exposure in the subjects. Fourth, in many cases, elementary school baseball players are not limited to being pitchers, but may also play in multiple positions, and therefore baseball players are not solely pitchers. Fifth, the age, height, and weight of our subjects differed. In this study, priority was given to the fact that all subjects were playing in similar leagues, but we must also consider other factors in the future while taking into account demographic parameters, such as age, height, and weight. Finally, external load factors, such as the total number of pitches and the number of innings pitched, were not evaluated in this study. These factors should be examined in future studies.

CONCLUSION

In the injured group, the hip external rotation on the dominant side, the hip internal rotation on the non-dominant side, and the ankle plantar flexion on the non-dominant side were significantly lower than in the non-injured group. These results may suggest measures to help reduce the incidence of these injuries.

DATA AVAILABILITY

The datasets generated during this study and/or the data analyzed during the current study are not publicly available based on a decision of the ethics committee of our university. However, such data are available from the corresponding

author on reasonable request.

ACKNOWLEDGMENTS

We thank the personnel, players, coaches, and staff of the Gunma Prefecture Elementary School Baseball Federation for their assistance and cooperation in this study.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest in association with the present study.

REFERENCES

1. Takagishi K, Matsuura T, Masatomi T, Chosa E, Tajika T, Iwama T, Watanabe M, Otani T, Inagaki K, Ikegami H, Aoki M, Okuwaki T, Kameyama Y, Akira M, Kaneoka K, Sakamoto M, Beppu M: Shoulder and elbow pain in junior high school baseball players: results of a nationwide survey. *J Orthop Sci* 2019;24:708–714. DOI:10.1016/j.jos.2018.12.018, PMID:30638688
2. Sakata J, Nakamura E, Suzukawa M, Akaike A, Shimizu K: Physical risk factors for a medial elbow injury in junior baseball players: a prospective cohort study of 353 players. *Am J Sports Med* 2017;45:135–143. DOI:10.1177/0363546516663931, PMID:27604190
3. Wilk KE, Macrina LC, Fleisig GS, Porterfield R, Simpson CD II, Harker P, Paparesta N, Andrews JR: Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *Am J Sports Med* 2011;39:329–335. DOI:10.1177/0363546510384223, PMID:21131681
4. Bushnell BD, Anz AW, Noonan TJ, Torry MR, Hawkins RJ: Association of maximum pitch velocity and elbow injury in professional baseball pitchers. *Am J Sports Med* 2010;38:728–732. DOI:10.1177/0363546509350067, PMID:20093420
5. 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;38:1375–1382. DOI:10.1177/0363546509360404, PMID:20489215

6. Shitara H, Kobayashi T, Yamamoto A, Shimoyama D, Ichinose T, Tajika T, Osawa T, Iizuka H, Takagishi K: Prospective multifactorial analysis of preseason risk factors for shoulder and elbow injuries in high school baseball pitchers. *Knee Surg Sports Traumatol Arthrosc* 2017;25:3303–3310. DOI:10.1007/s00167-015-3731-4, PMID:26239860
7. Thompson SF, Guess TM, Plackis AC, Sherman SL, Gray AD: Youth baseball pitching mechanics: a systematic review. *Sports Health* 2018;10:133–140. DOI:10.1177/1941738117738189, PMID:29090988
8. Fleisig GS, Barrentine SW, Zheng N, Escamilla RF, Andrews JR: Kinematic and kinetic comparison of baseball pitching among various levels of development. *J Biomech* 1999;32:1371–1375. DOI:10.1016/S0021-9290(99)00127-X, PMID:10569718
9. 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;43:752–758. DOI:10.2519/jospt.2013.4680, PMID:24256174
10. Feigenbaum LA, Roach KE, Kaplan LD, Lesniak B, Cunningham S: The association of foot arch posture and prior history of shoulder or elbow surgery in elite-level baseball pitchers. *J Orthop Sports Phys Ther* 2013;43:814–820. DOI:10.2519/jospt.2013.4504, PMID:24175593
11. Saito M, Kenmoku T, Kameyama K, Murata R, Yusa T, Ochiai N, Kijima T, Takahira N, Fukushima K, Ishige N, Takaso M: Relationship between tightness of the hip joint and elbow pain in adolescent baseball players. *Orthop J Sports Med* 2014;2: 2325967114532424. DOI:10.1177/2325967114532424, PMID:26535327
12. Sekiguchi T, Hagiwara Y, Yabe Y, Tsuchiya M, Itaya N, Yoshida S, Yano T, Sogi Y, Suzuki K, Itoi E: Restriction in the hip internal rotation of the stride leg is associated with elbow and shoulder pain in elite young baseball players. *J Shoulder Elbow Surg* 2020;29:139–145. DOI:10.1016/j.jse.2019.07.004, PMID:31521523
13. Tajika T, Kobayashi T, Yamamoto A, Kaneko T, Shitara H, Shimoyama D, Iizuka Y, Okamura K, Yonemoto Y, Warita T, Ohsawa T, Nakajima I, Iizuka H, Takagishi K: A clinical and ultrasonographic study of risk factors for elbow injury in young baseball players. *J Orthop Surg (Hong Kong)* 2016;24:45–50. DOI:10.1177/230949901602400112, PMID:27122512
14. Shitara H, Yamamoto A, Shimoyama D, Ichinose T, Sasaki T, Hamano N, Ueno A, Endo F, Oshima A, Sakane H, Tachibana M, Tomomatsu Y, Tajika T, Kobayashi T, Osawa T, Iizuka H, Takagishi K: Shoulder stretching intervention reduces the incidence of shoulder and elbow injuries in high school baseball players: a time-to-event analysis. *Sci Rep* 2017;7:45304. DOI:10.1038/srep45304, PMID:28345616
15. Camp CL, Zajac JM, Pearson D, Wang D, Sinatro AS, Ranawat AS, Dines JS, Coleman SH: The impact of workload on the evolution of hip internal and external rotation in professional baseball players over the course of the season. *Orthop J Sports Med* 2018;6:2325967117752105. DOI:10.1177/2325967117752105, PMID:29435468
16. Davis JT, Limpisvasti O, Fluhme D, Mohr KJ, Yocum LA, Elattrache NS, Jobe FW: The effect of pitching biomechanics on the upper extremity in youth and adolescent baseball pitchers. *Am J Sports Med* 2009;37:1484–1491. DOI:10.1177/0363546509340226, PMID:19633301
17. Steinberg N, Hershkovitz I, Peleg S, Dar G, Masharawi Y, Heim M, Siev-Ner I: Range of joint movement in female dancers and nondancers aged 8 to 16 years: anatomical and clinical implications. *Am J Sports Med* 2006;34:814–823. DOI:10.1177/0363546505281805, PMID:16382012
18. 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;37:566–570. DOI:10.1177/0363546508326712, PMID:19059890
19. Frank C, Kobesova A, Kolar P: Dynamic neuromuscular stabilization & sports rehabilitation. *Int J Sports Phys Ther* 2013;8:62–73. PMID:23439921
20. Li X, Ma R, Zhou H, Thompson M, Dawson C, Nguyen J, Coleman S: Evaluation of hip internal and external rotation range of motion as an injury risk factor for hip, abdominal and groin injuries in professional baseball players. *Orthop Rev (Pavia)* 2015;7:6142. DOI:10.4081/or.2015.6142, PMID:26793294
21. Krajnik S, Fogarty KJ, Yard EE, Comstock RD: Shoulder injuries in US high school baseball and softball athletes, 2005–2008. *Pediatrics* 2010;125:497–501. DOI:10.1542/peds.2009-0961, PMID:20142288

22. Crawford EA, Whiteside D, Deneweth JM, Ross JR, Bedi A, Goulet GC: In vivo hip morphology and kinematics in elite baseball pitchers. *Arthroscopy* 2016;32:798–805. DOI:10.1016/j.arthro.2015.11.052, PMID:26972629
23. Kibler WB, Wilkes T, Sciascia A: Mechanics and pathomechanics in the overhead athlete. *Clin Sports Med* 2013;32:637–651. DOI:10.1016/j.csm.2013.07.003, PMID:24079426
24. Weber AE, Kontaxis A, O'Brien SJ, Bedi A: The biomechanics of throwing: simplified and cogent. *Sports Med Arthrosc Rev* 2014;22:72–79. DOI:10.1097/JSA.0000000000000019, PMID:24787720
25. Dillman CJ, Fleisig GS, Andrews JR: Biomechanics of pitching with emphasis upon shoulder kinematics. *J Orthop Sports Phys Ther* 1993;18:402–408. DOI:10.2519/jospt.1993.18.2.402, PMID:8364594
26. Rabin A, Portnoy S, Kozol Z: The association of ankle dorsiflexion range of motion with hip and knee kinematics during the lateral step-down test. *J Orthop Sports Phys Ther* 2016;46:1002–1009. DOI:10.2519/jospt.2016.6621, PMID:27686412
27. Kung SM, Shultz SP, Kontaxis A, Kraszewski AP, Gibbons MW, Backus SI, Fink PW, Fealy S, Hillstrom HJ: Changes in lower extremity kinematics and temporal parameters of adolescent baseball pitchers during an extended pitching bout. *Am J Sports Med* 2017;45:1179–1186. DOI:10.1177/0363546516687289, PMID:28157450
28. Basnett CR, Hanish MJ, Wheeler TJ, Miriovsky DJ, Danielson EL, Barr JB, Grindstaff TL: Ankle dorsiflexion range of motion influences dynamic balance in individuals with chronic ankle instability. *Int J Sports Phys Ther* 2013;8:121–128. PMID:23593550
29. Rabin A, Kozol Z: Weightbearing and nonweight-bearing ankle dorsiflexion range of motion: are we measuring the same thing? *J Am Podiatr Med Assoc* 2012;102:406–411. DOI:10.7547/1020406, PMID:23001734
30. Lyman S, Fleisig GS, Waterbor JW, Funkhouser EM, Pulley L, Andrews JR, Osinski D, Roseman JM: Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Med Sci Sports Exerc* 2001;33:1803–1810. DOI:10.1097/00005768-200111000-00002, PMID:11689728
31. Fleisig GS, Andrews JR, Cutter GR, Weber A, Loftice J, McMichael C, Hassell N, Lyman S: Risk of serious injury for young baseball pitchers: a 10-year prospective study. *Am J Sports Med* 2011;39:253–257. DOI:10.1177/0363546510384224, PMID:21098816

APPENDIX 1: QUESTIONS ASKED OF THE PLAYERS

Checklist for little league players

	Yes	No
History of pain in the pitching arm		
Mark the parts of your body that have felt sore at any point since you started playing baseball.		
1. Shoulder	1	0
2. Elbow	1	0
Present pain in the pitching arm		
Mark the parts of your body that hurt at present.		
1. Shoulder	1	0
2. Elbow	1	0