JSES International 8 (2024) 570–576

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

Investigation of the limiting factors of shoulder joint complex motion in college baseball players: motion analysis of the humeral head and rotator cuff using ultrasound

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A R T I C L E I N F O

Keywords:
Ultrasonography
Particle image velocimetry
Motion analysis
Shoulder
Glenohumeral joint
Infraspinatus

Level of evidence: Basic Science Study; Kinesiology

Background: The relationship between lower mobility, as measured by the elbow forward translation motion (T-motion) test, a new indicator of shoulder joint complex movement that measures elbow position when both dorsal hands are placed on the iliac crest while in a sitting position, and the parameters calculated by ultrasonography is unknown. The purpose of this study was to investigate the limiting factors of T-motion through motion analysis of the humeral head and rotator cuff muscles using ultrasonography in college baseball players.
Methods: Thirteen college baseball players participated in this cross-sectional study. The shortest distance from the posterior edge of the glenoid to the humeral head was measured in the static and T-motion positions, and the difference was calculated as the humeral head translation. The velocity of the infraspinatus was calculated during shoulder internal/external rotation using the particle image velocimetry method. These parameters were compared between the throwing and nonthrowing sides to examine the limiting factors of T-motion.
Results: This study indicated moderate-to-good reliability for the parameters calculated by ultrasonography. The mean anterior translation distance was significantly greater on the throwing side than on the nonthrowing side ($r = 0.56$, $P = .015$). The mean velocity of infraspinatus during internal rotation was significantly lower on the throwing side than on the nonthrowing side ($r = 0.51$, $P = .028$).
Conclusion: Increased anterior translation of the humeral head and decreased the velocity of infraspinatus are likely correlated with reduced T-motion mobility in college baseball players. These methods showed potential for physical therapy assessment and intervention to prevent shoulder dysfunction.

The shoulder joint is a complex of multiple joints that allows for a significant degree of mobility and plays a pivotal role in activities of daily living and sports. Washing and dressing involve upper limb movements that require extensive mobility and complex shoulder joint motion.[22] In addition, sports involving overhead movements require greater mobility and complex motions of the shoulder joint.[6] Therefore, there is a need to establish an indicator for complex shoulder movements for the evaluation of both shoulder dysfunction and actual movements in clinical practice.

One method of evaluating complex motion of the shoulder joint in clinical practice, the elbow forward translation motion (T-motion) test, has been developed.[31] This test provides a quick and simple means to measure an individual's elbow position while seated with both hands on the iliac crest and the elbow actively moving forward. The T-motion test has demonstrated associations with shoulder internal rotation (IR) and external rotation (ER) and functional scores on activities of daily living in patients with rotator cuff tears.[31] Given that T-motion has previously been linked to rotational movement, it is plausible that factors such as stiffness in posterior tissues and other variables may act as limiting factors for this motion.

Ultrasonography provides the ability to assess patients repeatedly and dynamically without any invasion or radiation exposure. Ultrasonography-based quantitative analysis has demonstrated its potential for evaluating the translation of the humeral head with

The ethics committee of the Faculty of Medicine, Kagoshima University, approved the study protocol (ref no. 220018).

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https://doi.org/10.1016/j.jseint.2023.12.012
2666-6383/

high reproducibility in cadaveric studies.[27] In general, according to glenohumeral joint arthrokinematics, humeral head translation is known to occur during almost any movement.[33] In addition, a previous report revealed that patients with anterior shoulder instability exhibit greater anterior translation.[9] Given that translation of the humeral head is thought to occur during complex shoulder movements, an evaluation is deemed necessary. Furthermore, particle image velocimetry (PIV), a fluid engineering technique capable of visualizing fluid velocity, has garnered attention in the orthopedic field for dynamic analysis.[11,12,25,28] In orthopedics, PIV has been used to investigate the relationship between fascial gliding and postoperative pain after proximal femoral fracture surgery.[12] Additionally, the PIV technique has been applied in patients with frozen shoulders, revealing decreased coracohumeral ligament velocity during shoulder IR and ER[11] and decreased velocity, indicating decreased flexibility of the tissue. Consequently, the use of the PIV method for ultrasonography allows for dynamic evaluation of tendons and ligaments, and we believe that PIV could also be applied in the assessment of rotator cuff muscles.

Throwing is a typical movement in overhead sports, [6] and baseball players have a limited range of motion (ROM) due to increased stiffness in the posterior tissues on the throwing side.[17,26] Since throwing involves IR, the posterior rotator cuff is easily overloaded, and tightness of the infraspinatus (ISP) muscle has been reported.[1,17] Posterior tightness is thought to contribute to an anterior shift of the humeral head, which may lead to abnormal shoulder joint dynamics during the throwing motion, potentially causing injury. Using ultrasound to visualize and quantify the motion of the humeral head and ISP during shoulder movement may be useful for injury prevention. Motion analysis of the humeral head and rotator cuff muscles during shoulder-joint complex movements may help elucidate limiting factors of the rotator cuff muscles. However, these factors, as well as the detailed tissue mechanisms underlying deficits in shoulder complex movement, remain elusive.

Therefore, the purpose of this study was to investigate the limiting factors of T-motion through motion analysis of the humeral head and rotator cuff muscles using ultrasound imaging in college baseball players. Our hypothesis is that increased anterior displacement of the humeral head and reduced rotator cuff muscle velocity are linked to T-motion limitations in college baseball players.

Materials and methods

Participants

In this study, 13 college baseball players volunteered to participate; their average age was 21.5 ± 1.0 years, height was 1.74 ± 0.07 m, weight was 65.2 ± 7.4 kg, and baseball career duration was 11.3 ± 2.7 years. All participants were from one university competing at an amateur-level players participating in student leagues in the district. Among the participants, 6 were pitchers and 7 were fielders. All players were right-handed and engaged in club activities, exercising for 2-3 hours at least 2-3 times a week. The exclusion criteria were as follows: (i) a history of shoulder or elbow surgery, (ii) the presence of significant injuries, inability to participate in practice or games at the time of examination. Informed consent was obtained from all participants before their inclusion in the study, and the ethics committee of the Faculty of Medicine at Kagoshima University approved the study protocol (ref no. 220018). To determine the sample size, a power analysis was conducted using G*Power 3.1.9 (Heinrich Heine Universität, Düsseldorf, Germany) based on a previous report that analyzed the velocity of soft tissue in the shoulder using PIV and compared both sides.[11] Sample size calculations indicated that a sample size of 12 participants would be sufficient to detect differences using a t test (effect size, d = 0.8; significance level, $\alpha = 0.05$; power, 0.8).

Evaluation by the elbow forward T-motion test

The T-motion test, a quick and simple assessment, measures the elbow position when both dorsal hands are placed on top of the iliac crest while the patient is in a sitting position and the elbow is actively moved forward.[31] During T-motion, patients were asked to avoid kyphosis as a means of inhibiting compensatory movements.[31] A positive test result was defined as a position of the olecranon posterior to the body on the sagittal plane, while a negative test result was defined as a position of the olecranon anterior to the body on the sagittal plane. In this study, all participants had negative results on the T-motion test, indicating that flexibility was ensured. However, in every participant, the olecranon was positioned more posteriorly on the throwing side than on the nonthrowing side (Fig. 1). These findings suggest increased stiffness on the throwing side compared to the nonthrowing side.

Experimental data acquisition and analysis

Measurements were taken with participants seated upright in chairs, maintaining a neutral shoulder position; their arms were at their sides with 0 degrees of abduction and adduction, and their forearms rested on their thighs. Additionally, participants were instructed to rotate their shoulders 30 degrees internally and relax, ensuring a consistent posture across all measurements and preventing muscle and capsule tension.[26] An ultrasound transducer with a center frequency of 10 MHz (SONIMAGE HS1; Konica Minolta) was used; this transducer provided measurements with an accuracy of less than 0.2 mm, and a single physical therapist conducted all the sonographies.[21] Two examinations were performed on each shoulder, maintaining uniform depth and dynamic range settings for all measurements. To measure humeral head translation, we positioned the ultrasound transducer on the posterior aspect of the shoulder and obtained a long-axis scan of the ISP (Fig. 2, *A*).[26] We then adjusted the transducer's position to ensure clear visualization of the humeral head, glenoid rim, and ISP. In addition, the transducer was similarly adjusted to the neutral position at the starting position for the T-motion test (Fig. 2, *B*).

To measure anterior translation, following the method described in a previous study,[9] we calculated the shortest distance between 2 lines drawn through the posterior edges of the glenoid and the humeral head. These measurements were taken at both the static position and the T-motion position. When the posterior edge of the humeral head was anteriorly aligned with the posterior edge of the glenoid, the static and T-motion distances were assigned negative values. The distance of anterior translation (D_{AT}) was then calculated by subtracting the T-motion distance from the static distance (Fig. 3).

For motion analysis, we focused on the ISP, which is known to exhibit stiffness on the throwing side,[17] during both shoulder IR and ER. We positioned a linear array transducer 2 cm above and below the center of the scapula spine.[17] Shoulder joint movements were performed actively with 0 degrees of abduction and 0 degrees of anterior elevation. Initially, the shoulder was moved from 0 to 60 degrees of IR, following a rhythm of one repetition every 2 seconds, guided by a metronome.[11] We then used PIV fluid measurement software (PIVlab, Version 2.36, an add-in software from MATLAB 2021, MathWorks, Natick, MA, USA) to analyze the velocity of ISP

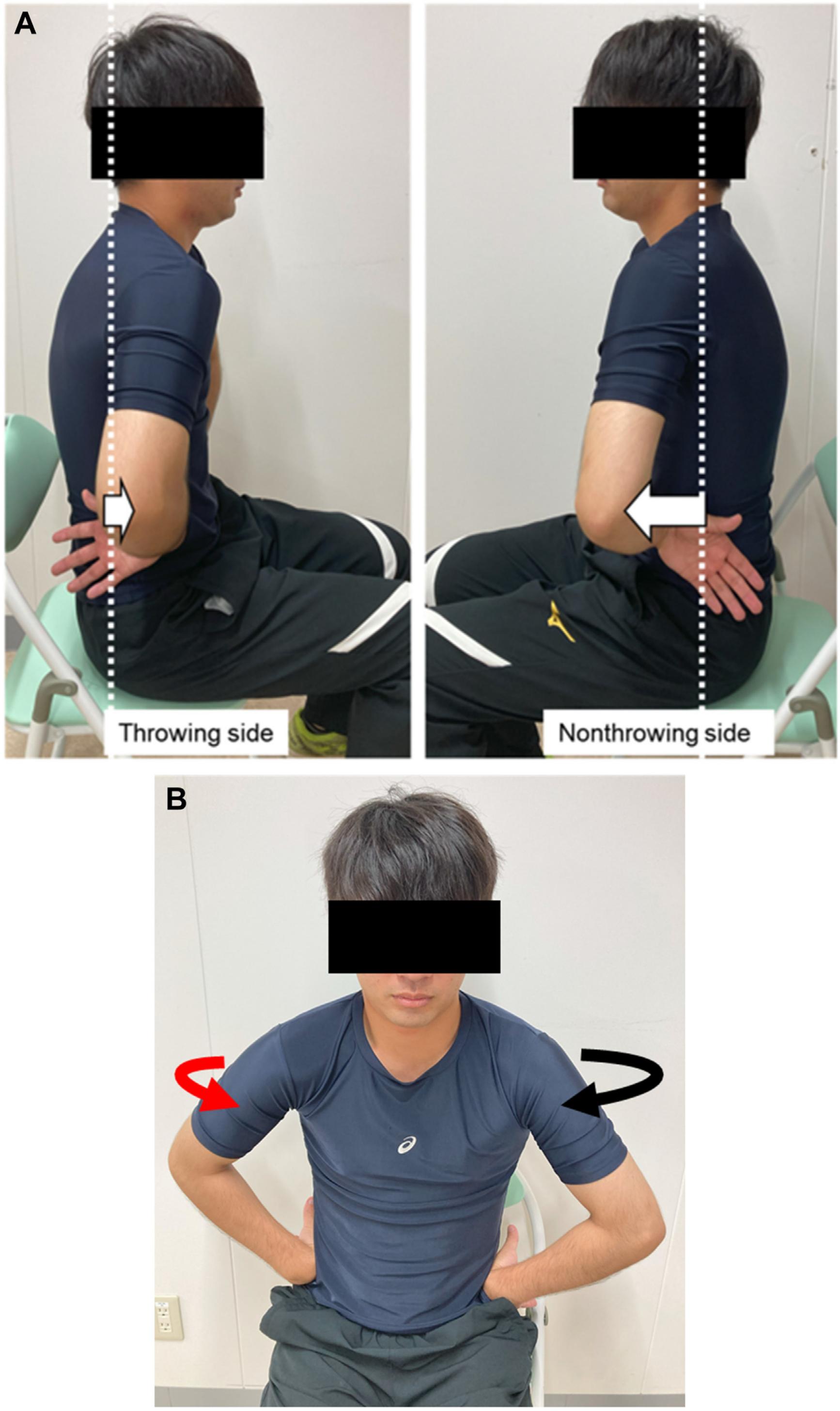

Figure 1 Evaluation of the T-motion test. (**A**) End position on the sagittal plane on the throwing and nonthrowing sides. A positive result was defined as a position of the olecranon posterior to the body on the sagittal plane (indicating decreased mobility), while a negative result was defined as a position of the olecranon anterior to the body (indicating adequate mobility). (**B**) End position on the coronal plane. In this study, all participants were classified as negative, indicating that flexibility was ensured. However, the olecranon was positioned more posteriorly on the throwing side than on the nonthrowing side (*red arrow*), suggesting increased stiffness on the throwing side compared to the normal shoulder. *T-motion*, translation motion.

motion.[29,30] To facilitate analysis, we divided all the ultrasound movies into 30 static images per second. We measured the pixel displacement between 2 consecutive images and subsequently calculated the velocity of the structures within the region of interest (Fig. 4). The analysis yielded both average and maximum velocities of ISP motion during IR and ER.

Measurements of glenohumeral ROM

We measured the passive glenohumeral ROM for both IR and ER at two specific positions: 90 degrees of shoulder abduction (referred to as 2nd IR and ER) and 90 degrees of shoulder abduction and flexion (referred to as third IR and ER). These measurements

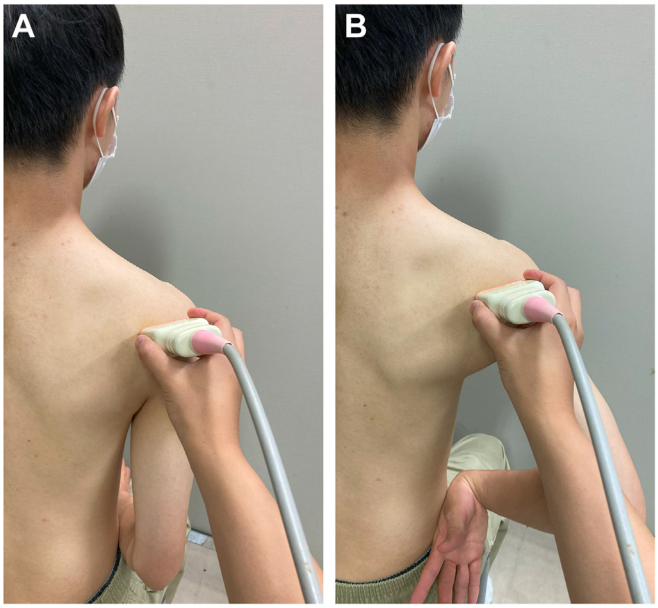

Figure 2 The participants' positions during ultrasound examination of humeral head translation (**A**) in the static position and (**B**) in the T-motion position. *T-motion*, translation motion.

were taken using a goniometer while participants were in a supine position. These ROMs are often measured to assess posterior shoulder tightness, as referenced in previous studies.[17,20,26] During the measurements, the operator ensured that the participants' scapulae were restrained with their hand, immobilizing the scapulothoracic joint.[19] This approach aimed to maximize the isolated motion of the glenohumeral joint.

Statistical analysis

To assess reproducibility, we calculated the intraclass correlation coefficient (ICC (1, 2)) of these measurements. ICCs were interpreted according to the criteria from a prior study: <0.50 indicated poor reliability, 0.50 to 0.75 indicated moderate reliability, 0.76 to 0.90 indicated good reliability, and >0.90 indicated excellent reliability.[14] We employed t tests and Mann–Whitney tests to compare the parameters between the throwing and nonthrowing sides. For between-group comparisons, we calculated the effect size (r), which was categorized as trivial (<0.20), small (0.20-0.50), medium (0.50-0.80), or large (>0.80).[3] To explore the relationships between humeral head translation and the velocity of the ISP and the ROM, we calculated Pearson and Spearman correlation coefficients. All the statistical analyses were conducted using SPSS 28 (IBM Corp., Armonk, NY, USA), and the significance level was set at 5%.

Results

The reliability data for the ultrasound measurements are presented in Table I. The D_{AT} measurements demonstrated excellent reliability, while the ISP velocity showed moderate-to-good reliability overall, except for IR on the nonthrowing side (Table I). The mean static distance was 4.86 ± 2.0 mm on the throwing side and 5.59 ± 2.1 mm on the nonthrowing side, with no significant difference observed between the two sides (P = .166, r = 0.27: medium; Fig. 4). The mean T-motion distance was significantly shorter on the throwing side (2.29 ± 1.7 mm) than on the nonthrowing side (5.78 ± 3.0 mm) (P < .001, r = 0.78: large; Fig. 5), and the mean D_{AT} was significantly greater on the throwing side (2.57 ± 2.5 mm) than on the nonthrowing side (−0.20 ± 2.6 mm) (P = .015, r = 0.56: large; Fig. 5).

The mean velocity of ISP during IR was 1.29 ± 0.4 mm/s on the throwing side and 1.48 ± 0.3 mm/s on the nonthrowing side, indicating a significantly slower velocity on the throwing side (P = .028, r = 0.51: large; Fig. 6). The maximum velocity of ISP during IR was 5.88 ± 3.3 mm/s on the throwing side and 7.26 ± 3.5 mm/s on the nonthrowing side, indicating a trend toward a slower velocity on the throwing side (P = .087, r = 0.37: medium; Fig. 6). For the velocity of ISP during ER, both the mean (throwing, 1.41 ± 0.6 mm/s; nonthrowing, 1.36 ± 0.3 mm/s; r = 0.09: trivial) and maximum (throwing, 6.66 ± 5.8 mm/s; nonthrowing, 7.04 ± 3.7 mm/s; r = 0.18: small) velocities showed no significant differences between the 2 sides ($P \geq .370$).

In terms of the relationships between the ultrasound parameters on the throwing side, the T-motion distance was correlated with the mean velocity during IR (r = −677, P = .011) and ER (r = −561, P = .046). The T-motion distance also correlated with the maximum velocity during IR (r = −616, P = .025) and ER (r = −637, P = .019). The nonthrowing side did not exhibit any relationship.

Regarding the glenohumeral ROM, the second IR and third IR and ER were significantly smaller on the throwing side than on the nonthrowing side, and the second ER was significantly larger (Table II). Additionally, the maximum velocity of the ISP during IR was correlated with the third IR angle on the throwing side (r = .559, P = .047). Furthermore, the maximum velocity of the ISP during IR (r = .550, P = .051) and ER (r = .486, P = .092) tended to correlate with the second ER angle on the throwing side.

Discussion

In this study, we investigated the limiting factors associated with the T-motion test, a representation of complex shoulder motion, by dynamically analyzing the humeral head and rotator cuff muscles in college baseball players via ultrasonography. Our findings revealed that increasing anterior displacement of the humeral head and decreasing ISP velocity were correlated with reduced mobility in T-motion. This motion analysis of the humeral head and rotator cuff muscles using ultrasonography demonstrated the potential for quantifying movement within the shoulder joint complex. These findings underscore the clinical relevance and utility of this approach in understanding shoulder mobility and dysfunction.

Regarding the glenohumeral ROM, the second IR and third IR and ER were significantly smaller on the throwing side than on the nonthrowing side, and the second ER was significantly larger. These results showed large effect sizes and were similar to those of previous studies.[1,17] According to the results of the T-motion test, the muscles in the throwing side were shown to be stiffer. Therefore, the results of the comparison between the throwing and nonthrowing sides may have helped identify limiting factors for decreased mobility during shoulder complex motion.

Our results demonstrated moderate-to-good reliability of the ultrasound measurements. Previous reports have shown ICCs of 0.810 for humeral head translation in patients with shoulder instability[9] and 0.80 for the velocity of coracohumeral ligament in patients with frozen shoulder.[11] Therefore, the measurement method employed in the present study was capable of accurately calculating humeral head translation and ISP velocity. Furthermore, the differences observed between the throwing and nonthrowing sides were approximately 2.5 mm for D_{AT} and approximately 0.20 mm/s for the mean ISP velocity during IR. These values exceeded the measurement error, confirming the precision of these parameters.

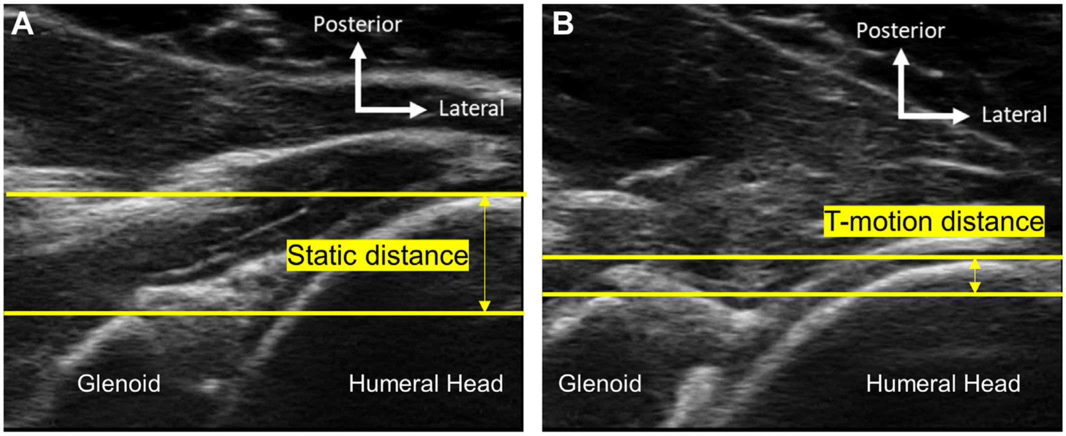

Figure 3 Ultrasound assessment of anterior translation in the glenohumeral joint. Two parallel lines (*yellow straight lines*) are drawn through the posterior edges of the glenoid and the humeral head, as shown in the (**A**) static position and (**B**) T-motion position. The static and T-motion distances represent the shortest distances measured between the 2 parallel lines (*vertical yellow lines with arrows*) pointing toward the humeral head. The difference between the static and T-motion distances was calculated as the distance of anterior translation. *T-motion*, translation motion.

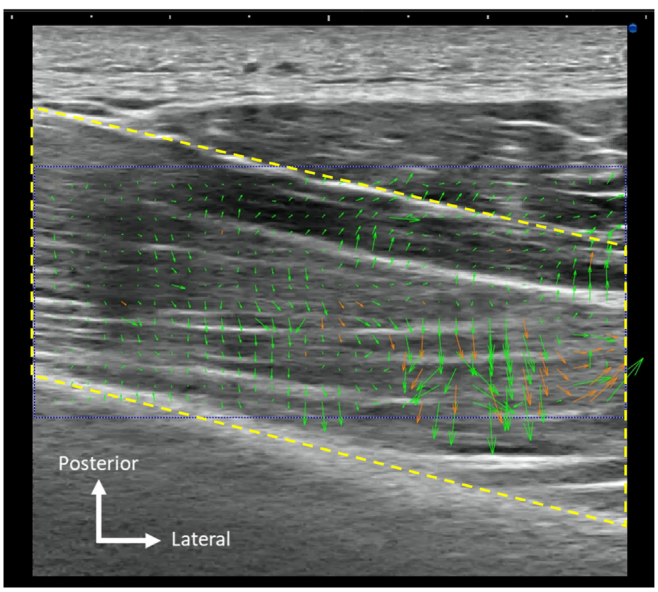

Figure 4 Flow PIV fluid measurement software tracking the movement of the ISP (*yellow dot square*) during internal rotation. The muscle belly of the ISP is indicated by the yellow square. The direction of the arrows (green and orange) inside the region of interest (*blue dot square*) indicates the direction in which the particle moves. *PIV*, particle image velocimetry; *ISP*, infraspinatus.

In the context of humeral head translation, the mean D_{AT} was significantly greater on the throwing side than on the contralateral side and had a moderate to large effect size. T-motion has been previously correlated with IR movement in patients with rotator cuff tears.[31] IR behind the back, as measured by the Constant-Murley score, consists of various components, including shoulder extension, adduction, elbow flexion, and IR of the glenohumeral joint.[4,5,16] This movement encompasses the incorporation of the humeral head,[7,15,33] posterior tightness,[24] and motion of the humerus and scapula.[7,15,16] Specifically, studies have indicated that the stiffness of the posterior capsule is associated with the loss of glenohumeral IR,[26] and tightening of the posterior capsule can result in greater anterior translation of the humeral head.[16] In this study, we observed that the mean D_{AT} was approximately −0.2 mm on the nonthrowing side, suggesting sufficient flexibility of the posterior tissues to enable posterior movement of the humeral head during the T-motion test. Cadaver studies have shown that substantial strain on the posterior capsule of the shoulder occurs during shoulder flexion with IR rather than during horizontal adduction or abduction.[2,10] Therefore, greater translation of the humeral head on the throwing side may have restricted the mobility during T-motion due to factors such as posterior tightening and other anatomical considerations.

In terms of the velocity of ISP during IR, we observed that the mean velocity was slower on the throwing side, indicating reduced flexibility, and that the effect size was moderate to large. These findings suggest that a decrease in ISP velocity during IR, a movement that involves lengthening of the ISP, may be correlated with the limitation of glenohumeral ROM. Typically, anatomical factors, including joint capsules, muscles, and ligaments, play a role in limiting the active ROM of the shoulder, as detailed in the literature.[8,10,18,19,23,32] Specifically, baseball players with posterior shoulder tightness have been reported to exhibit reduced glenohumeral IR and horizontal adduction ROM, along with increased muscle stiffness in the ISP and teres minor on the throwing side.[1,17] IR with mild elevation of the glenohumeral joint has been shown to stretch the ISP, teres minor, and posterior joint capsules.[8,10,18,23] These anatomical factors could also influence the mobility of T-motion. Furthermore, we found that the relationship between humeral head translation during T-motion on the throwing side was correlated with the velocity of the ISP during IR and ER. In addition, the maximum velocity of the ISP during IR was correlated with the third IR angle on the throwing side. These results indicated that deviant movement of the humeral head and rotator cuff muscle may be associated with decreased mobility in shoulder complex movements. This study suggested that evaluating velocity of ISP, in addition to assessing changes in glenohumeral ROM, is essential for understanding the factors associated with improved shoulder ROM. Since the identification of limiting factors with goniometry alone is unclear, we believe that these ultrasound assessments will help visualize limiting factors of shoulder ROM, such as ISP, in clinical practice.

This study has several noteworthy limitations. First, due to its cross-sectional design, establishing causal relationships between the parameters and the feasibility of the T-motion test in baseball players remains unclear. Soft tissues other than muscles, such as the joint capsule, are also possible limiting factors for T-motion. Further prospective studies are warranted to identify specific

Table I
Reliability of the ultrasound measurements.

		Throwing side	Nonthrowing side
D_{AT}	ICC $_{(1,2)}$ (95% CI)	0.998 (0.996-0.999)	0.993 (0.979-0.998)
	measurement error (mm)	0.12	0.32
IR			
Average	ICC $_{(1,2)}$ (95% CI)	0.948 (0.836-0.984)	0.826 (0.452-0.946)
	measurement error (mm/s)	0.12	0.13
Maximum	ICC $_{(1,2)}$ (95% CI)	0.900 (0.684-0.969)	0.623 (−0.188-0.884)
	measurement error (mm/s)	1.30	2.36
ER			
Average	ICC $_{(1,2)}$ (95% CI)	0.898 (0.679-0.969)	0.947 (0.834-0.984)
	measurement error (mm/s)	0.24	0.10
Maximum	ICC $_{(1,2)}$ (95% CI)	0.714 (0.100-0.912)	0.876 (0.609-0.962)
	measurement error (mm/s)	3.10	1.76

D_{AT}, distance of anterior translation; *ICC $_{(1,2)}$*, intraclass correlation coefficient; *CI*, confidence interval; *IR*, internal rotation; *ER*, external rotation.

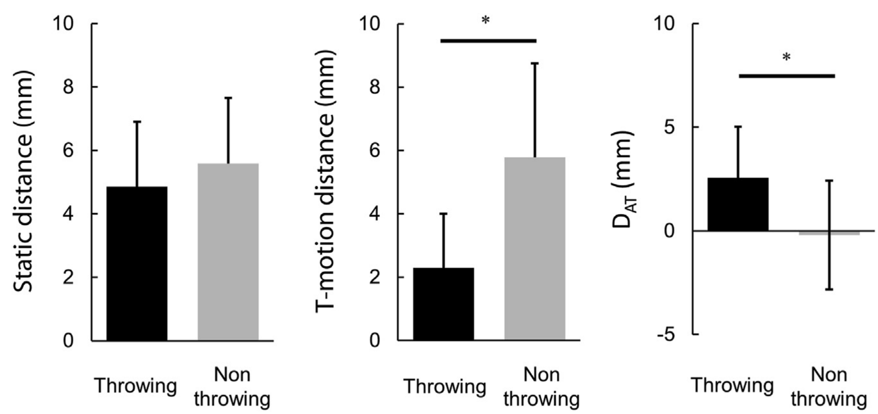

Figure 5 A comparison of humeral head translation. *D_{AT}*, distance of anterior translation (*P < .05).

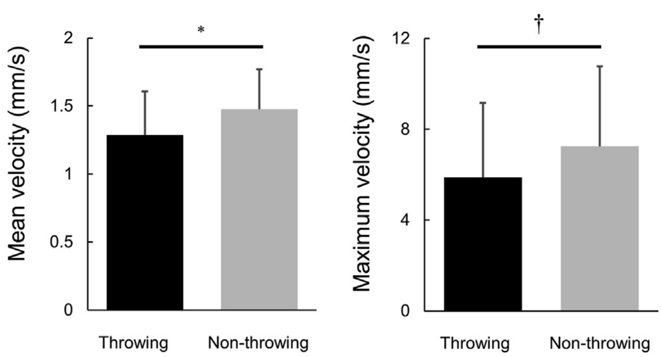

Figure 6 A comparison of the velocities of ISP velocities. The mean velocity of ISP velocity during IR was 1.29 ± 0.4 mm/s on the throwing side and 1.48 ± 0.3 mm/s on the nonthrowing side. The maximum velocity of ISP during IR was 5.88 ± 3.3 mm/s on the healthy side and 7.26 ± 3.5 mm/s on the nonthrowing side (*P < .05; †P < .10). *ISP*, infraspinatus; *IR*, internal rotation.

factors influencing this movement and to explore correlations with anatomical factors such as shoulder joint capsules and retrotorsion of the humerus. Second, T-motion is classified as a binary value and needs to be quantified for further study. Third, a large effect size was observed in each comparison, but the relatively small sample size in this study may have contributed to the notable variability in the outcome measures. Despite these limitations, motion analysis of humeral head translation and velocity of muscle using ultrasound holds promise for quantifying T-motion and providing a comprehensive evaluation of the effectiveness of ROM improvement in clinical settings. Furthermore, recent developments have led to the classification of limited shoulder joint ROM with shoulder disease as secondary stiff shoulder, as observed in conditions such as rotator cuff tears.[13] However, further studies are needed to examine the relationships between these ultrasound assessments and pitching motion and between these assessments and the measurements of patients with rotator cuff tears. In the future, we would like to work on setting reference values in the target population.

Conclusion

Our study indicated that an increase in anterior translation of the humeral head and a decrease in velocity of ISP correlate with reduced mobility in T-motion among college baseball players. This motion analysis of the humeral head and rotator cuff muscles using ultrasonography demonstrated the potential of ultrasonography for quantifying shoulder joint complex movement. Understanding the pathological translation of the humeral head and the dysfunction of rotator cuff muscles would be valuable for physical therapy assessment and intervention to prevent shoulder dysfunction.

Disclaimers:

Funding: This work was supported by JSPS KAKENHI (grant number JP22K09309).
Conflicts of interest: The 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.

Table II
Comparisons of glenohumeral range of motion.

	Throwing side	Nonthrowing side	*P* value	Effect size
Second position				
IR	48.1 ± 15.6	65.8 ± 8.9	<.001	0.86
ER	94.2 ± 7.0	87.3 ± 6.7	<.001	0.91
Third position				
IR	20.4 ± 9.0	29.2 ± 10.2	<.001	0.78
ER	142.3 ± 17.6	153.1 ± 9.5	<.001	0.93

IR, internal rotation; *ER*, external rotation.
The values are expressed as the means ± SDs.

Acknowledgments

The authors are grateful for Dr. Yutaka Mifune and Dr. Atsuyuki Inui, affiliated with the Department of Orthopaedic Surgery, Kobe University, who provided technical assistance with ultrasonography.

References

1. Bailey LB, Shanley E, Hawkins R, Beattie PF, Fritz S, Kwartowitz D, et al. Mechanisms of shoulder range of motion deficits in asymptomatic baseball players. Am J Sports Med 2015;43:2783-93. https://doi.org/10.1177/0363546515602446.
2. Borstad JD, Dashottar A. Quantifying strain on posterior shoulder tissues during 5 simulated clinical tests: a cadaver study. J Orthop Sports Phys Ther 2011;41:90-9. https://doi.org/10.2519/jospt.2011.3357.
3. Cohen J. Statistical power analysis for the behavioral sciences, 2013. 2nd ed. Hillsdale, NJ: Erlbaum.
4. Constant CR, Gerber C, Emery RJ, Sojbjerg JO, Gohlke F, Boileau P. A review of the constant score: modifications and guidelines for its use. J Shoulder Elbow Surg 2008;17:355-61. https://doi.org/10.1016/j.jse.2007.06.022.
5. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res 1987;214:160-4.
6. Diffendaffer AZ, Bagwell MS, Fleisig GS, Yanagita Y, Stewart M, Cain EL Jr, et al. The clinician's guide to baseball pitching biomechanics. Sports Health 2023;15:274-81. https://doi.org/10.1177/19417381221078537.
7. Endo K, Yukata K, Yasui N. Influence of age on scapulo-thoracic orientation. Clin Biomech (Bristol, Avon) 2004;19:1009-13. https://doi.org/10.1016/j.clinbiomech.2004.07.011.
8. Hollmann L, Halaki M, Kamper SJ, Haber M, Ginn KA. Does muscle guarding play a role in range of motion loss in patients with frozen shoulder? Musculoskelet Sci Pract 2018;37:64-8. https://doi.org/10.1016/j.msksp.2018.07.001.
9. Inoue J, Takenaga T, Tsuchiya A, Okubo N, Takeuchi S, Takaba K, et al. Ultrasound assessment of anterior humeral head translation in patients with anterior shoulder instability: correlation with demographic, radiographic, and clinical data. Orthop J Sports Med 2022;10:23259671221101924. https://doi.org/10.1177/23259671221101924.
10. Izumi T, Aoki M, Muraki T, Hidaka E, Miyamoto S. Stretching positions for the posterior capsule of the glenohumeral joint: strain measurement using cadaver specimens. Am J Sports Med 2008;36:2014-22. https://doi.org/10.1177/0363546508318196.
11. Kato T, Inui A, Mifune Y, Nishimoto H, Yoshikawa T, Shinohara I, et al. Dynamic analysis of the coracohumeral ligament using ultra-sonography in shoulder contracture. Sensors (Basel) 2023;23:4015. https://doi.org/10.3390/s23084015.
12. Kawanishi K, Kudo S, Yokoi K. Relationship between gliding and lateral femoral pain in patients with trochanteric fracture. Arch Phys Med Rehabil 2020;101:457-63. https://doi.org/10.1016/j.apmr.2019.09.011.
13. Kobayashi T, Karasuno H, Sano H, Hamada J, Takase K, Tamai K, et al. Representative survey of frozen shoulder questionnaire responses from the Japan Shoulder Society: what are the appropriate diagnostic terms for primary idiopathic frozen shoulder, stiff shoulder or frozen shoulder? J Orthop Sci 2019;24:631-5. https://doi.org/10.1016/j.jos.2018.12.012.
14. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159-74.
15. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys Ther 2000;80:276-91.
16. Maier MW, Erhard S, Niklasch M, Bruckner T, Wolf SI, Zeifang F, et al. Three-dimensional motion analysis for validation of shoulder internal rotation. Arch Orthop Trauma Surg 2017;137:735-41. https://doi.org/10.1007/s00402-017-2656-4.
17. Mifune Y, Inui A, Nishimoto H, Kataoka T, Kurosawa T, Yamaura K, et al. Assessment of posterior shoulder muscle stiffness related to posterior shoulder tightness in college baseball players using shear wave elastography. J Shoulder Elbow Surg 2020;29:571-7. https://doi.org/10.1016/j.jse.2019.05.028.
18. Muraki T, Aoki M, Uchiyama E, Murakami G, Miyamoto S. The effect of arm position on stretching of the supraspinatus, infraspinatus, and posterior portion of deltoid muscles: a cadaveric study. Clin Biomech (Bristol, Avon) 2006;21:474-80. https://doi.org/10.1016/j.clinbiomech.2005.12.014.
19. Muraki T, Aoki M, Uchiyama E, Takasaki H, Murakami G, Miyamoto S. A cadaveric study of strain on the subscapularis muscle. Arch Phys Med Rehabil 2007;88:941-6. https://doi.org/10.1016/j.apmr.2007.04.003.
20. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. Am J Sports Med 2006;34:385-91. https://doi.org/10.1177/0363546505281804.
21. Nakai Y, Oe K, Matsuno R, Kiyama R, Kawada M, Takeshita Y, et al. Effect of self-myofascial release of the lower back on myofascial gliding, lumbar flexibility, and abdominal trunk muscle strength: a crossover study. Sports (Basel) 2023;11:147. https://doi.org/10.3390/sports11080147.
22. Oosterwijk AM, Nieuwenhuis MK, van der Schans CP, Mouton LJ. Shoulder and elbow range of motion for the performance of activities of daily living: a systematic review. Physiother Theory Pract 2018;34:505-28. https://doi.org/10.1080/09593985.2017.1422206.
23. Rundquist PJ, Anderson DD, Guanche CA, Ludewig PM. Shoulder kinematics in subjects with frozen shoulder. Arch Phys Med Rehabil 2003;84:1473-9. https://doi.org/10.1016/s0003-9993(03)00359-9.
24. Salamh PA, Liu X, Kolber MJ, Hanney WJ, Hegedus EJ. The reliability, validity, and methodologic quality of measurements used to quantify posterior shoulder tightness: a systematic review of the literature with meta-analysis. J Shoulder Elbow Surg 2019;28:178-85. https://doi.org/10.1016/j.jse.2018.07.013.
25. Shinohara I, Inui A, Mifune Y, Nishimoto H, Yamaura K, Mukohara S, et al. Motion analysis of triangular fibrocartilage complex by using ultrasonography images: preliminary analysis. Sensors (Basel) 2022;22:345. https://doi.org/10.3390/s22010345.
26. 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.
27. Takeuchi S, Chan CK, Hattori S, Gibbs CM, Yamakawa S, Yano Y, et al. An improved quantitative ultrasonographic technique could assess anterior translation of the glenohumeral joint accurately and reliably. Knee Surg Sports Traumatol Arthrosc 2021;29:2595-605. https://doi.org/10.1007/s00167-021-06459-1.
28. Tanaka S, Inui A, Mifune Y, Nishimoto H, Yoshikawa T, Shinohara I, et al. Motion analysis of the extensor carpi ulnaris in triangular fibrocartilage complex injury using ultrasonography images. Sensors (Basel) 2022;22:8216. https://doi.org/10.3390/s22218216.
29. Thielicke W, Sonntag R. Particle image velocimetry for MATLAB: accuracy and enhanced algorithms in PIVlab. J Open Res Software 2021;9. https://doi.org/10.5334/jors.334.
30. Thielicke W, Stamhuis EJ. PIVlab – towards user-friendly, affordable and accurate digital particle image velocimetry in MATLAB. J Open Res Software 2014;2. https://doi.org/10.5334/jors.bl.
31. Uekama K, Miyazaki T, Maesako S, Kaieda H, Taniguchi N. Clinical significance of the elbow forward translation motion in patients with rotator cuff tears. JSES Int 2023;7:555-60. https://doi.org/10.1016/j.jseint.2023.02.019.
32. Walton J, Russell S. Physiotherapy assessment of shoulder stiffness and how it influences management. Shoulder Elbow 2015;7:205-13. https://doi.org/10.1177/1758573215586152.
33. Werner CM, Nyffeler RW, Jacob HA, Gerber C. The effect of capsular tightening on humeral head translations. J Orthop Res 2004;22:194-201. https://doi.org/10.1016/S0736-0266(03)00137-2.