Submitted: 01 October, 2025 Accepted: 28 November, 2025 Published: 30 March, 2026 DOI:10.22514/jomh.2026.026

JOMH
Journal of Men's Health

ORIGINAL RESEARCH

Kinematic predictors of shoulder torque efficiency: implications for injury risk in collegiate baseball pitchers

Maolin Dong[1,†], Xiaotao Guo[2,†], Nan Wang[1], Shuai Wang[3], Hao Hong[1,*], Sukwon Kim[3,*]

[1]College of Wushu, Henan University, 450046 Zhengzhou, Henan, China
[2]Department of Physical Education, Mahasarakham University, 44150 Maha Sarakham, Thailand
[3]Department of Physical Education, Jeonbuk National University, 54896 Jeonju, Republic of Korea

***Correspondence**
10320050@vip.henu.edu.cn
(Hao Hong);
rockwall@jbnu.ac.kr
(Sukwon Kim)

[†] These authors contributed equally.

Abstract

Background: High internal rotation torque on the shoulder joint during pitching is a major contributor to shoulder injuries. Biomechanical efficiency, which balances ball velocity against normalized joint torque, offers a valuable metric for improving performance and reducing injury. This study aimed to identify kinematic characteristics associated with shoulder internal rotation torque (IRT) biomechanical efficiency in collegiate baseball pitchers. **Methods**: We analyzed data from 68 male pitchers using multiple regression to assess relationships with 29 kinematic variables. The pitchers were also divided into high- and low-efficiency groups for comparative analysis. **Results**: Six variables were significantly associated with shoulder IRT efficiency, explaining 41.3% of its variance. Notably, the high-efficiency group exhibited a significantly smaller shoulder abduction angle at stride foot contact (SFC) ($83.87 \pm 6.7°$ *vs.* $89.19 \pm 8.75°$, $p = 0.022$) and a significantly larger shoulder external rotation angle at maximum external rotation (MER) ($171.3 \pm 8.33°$ *vs.* $165.2 \pm 9.50°$, $p = 0.027$). **Conclusions**: These results indicate that modifying these specific aspects of pitching mechanics may enhance biomechanical efficiency by reducing the standardized load on the shoulder joint relative to ball velocity, offering practical insights for injury prevention training. However, coaches should note that increasing the angle of shoulder external rotation should be achieved through controlled joint mobility rather than by excessively demanding greater external rotation angles to avoid increasing the risk of injury.

Keywords

Baseball pitching; Shoulder; Joint loading; Biomechanical efficiency; Kinematics

1. Introduction

Epidemiological studies indicate that shoulder overuse injuries are the most prevalent injury type among baseball players across all levels, accounting for 24% of all injuries. Notably, 73% of these shoulder injuries are triggered by the pitching motion, with severe cases often leading to prolonged absences from play [1–5]. Pitchers are particularly susceptible to overuse injuries due to the substantial torques and forces generated within and around the shoulder joint during high-velocity pitching. The repetitive application of high-intensity shoulder torques and forces can lead to progressive soft-tissue degeneration and eventual failure [6–9]. According to the "Kinetic Chain" principle, efficient baseball pitching requires sequential energy transfer from the lower extremities through the pelvis and torso to the pitching arm to generate high ball velocities [10–13]. Incorrect pitching mechanics can cause shoulder pain in pitchers due to inefficient energy transfer, resulting in excessive compensatory rotational torque [14, 15]. Identifying specific biomechanical patterns that contribute to high shoulder risk and reducing injury risk by correcting inefficient pitching motions has always been a focus for sports scientists, pitchers, coaches, and clinicians, as highlighted in recent comprehensive reviews of biomechanics in sports performance and injury prevention [16, 17].

Previous research suggests that a reduced pelvic opening angle (indicating delayed rotation) prior to stride foot contact (SFC) and early trunk rotation contributes to an abnormal increase in shoulder internal rotation torque (IRT) [18, 19]. Similarly, excessive contralateral trunk tilt (away from the pitching arm side) is a significant factor contributing to elevated shoulder IRT [20, 21]. Among adolescent pitchers, adopting a hand-on-top position and a closed-shoulder stance has been associated with reduced shoulder IRT and improved biomechanical efficiency [22]. The temporal relationship between pitching events is also predictive of shoulder IRT, which increases as the time interval between foot touchdown and peak pelvic rotation velocity decreases [23, 24]. Additional studies have investigated the relationship between upper limb loading and factors such as stride length, lead knee angle, and knee extension angular velocity [25–27]. Critically, among these identified biomechanical factors influencing shoulder IRT, kinematic features (*e.g.*, trunk tilt angle, pitching posture, event timing) are generally considered easier to train and modify [28].

An ideal pitching motion should, therefore, generate high ball velocities while minimizing the shoulder joint IRT. Biomechanical efficiency—defined as ball speed/normalized joint torque—is the key metric quantifying this balance. A combination of high ball velocity (indicating performance) and low normalized shoulder IRT (indicating lower injury risk) results in higher shoulder joint biomechanical efficiency. Biomechanical efficiency has been extensively employed to evaluate pitching mechanics related to the varus torque of the elbow joint in baseball, yet, systematic research on shoulder joint biomechanical efficiency remains lacking [29, 30]. This gap is significant given that shoulder IRT itself is a key injury risk factor. Furthermore, methodological variations across existing studies—including differences in data collection protocols, participant populations (*e.g.*, age/skill level), and efficiency calculation methods—hinder systematic comparison and identification of the most critical and pervasive risk or efficiency factors.

Therefore, this study aimed to systematically investigate the association between modifiable pitching kinematic characteristics and shoulder internal rotation torque (IRT) biomechanical efficiency. Specifically, we hypothesized that specific kinematic characteristics would be significantly associated with shoulder IRT biomechanical efficiency. Identifying modifiable kinematic characteristics associated with high shoulder IRT biomechanical efficiency will provide a concrete foundation for designing optimized pitching technique interventions [16]. Such interventions aim to maintain or increase ball velocity while effectively reducing shoulder joint overload risk.

2. Materials and methods

2.1 Participants

We retrospectively extracted subject data from Wasserberger's OpenBiomechanics Project database; all data collection took place during training assessments conducted at Driveline Baseball Lab (Phoenix, Arizona) prior to 2022 [31]. After excluding poor data we selected data from 68 college baseball pitchers for analysis. Statistical data for all subjects includes: age 20.6 $\pm$ 1.3 years, mass 88.77 $\pm$ 9.11 kg, height 1.84 $\pm$ 0.07 m, and pitching speed 38.19 $\pm$ 1.92 m/s (85.43 $\pm$ 4.29 mph). The Western IRB has granted ethical approval for all data collection procedures within the OpenBiomechanics Project (Western IRB #WB-DLR-115). After explaining the research procedures, potential risks and benefits, the researchers obtained the athletes' verbal confirmation of understanding and secured witnessed legal signatures.

2.2 Data collection procedures

At the Driveline Baseball Lab (Phoenix, Arizona), pitching data was collected using motion capture to evaluate athlete training. Following individualized warm-up routines—including foam rolling, static and dynamic stretching, resistance band exercises, and throwing—athletes removed loose clothing. Laboratory staff then placed 47 reflective markers on designated bony landmarks (locations shown in Fig. 1) [30]. Subsequently, pitchers were given additional time to acclimate to wearing the markers and pitching from the mound. Full experimental procedures are detailed in previously published papers [30, 32].

Once athletes indicated readiness, they threw maximum-effort fastballs, the trial with the fastest pitch speed was used for analysis. These were delivered from a standard mound towards a strike zone target (Oates Specialties, LLC) positioned 18.44 m away above home plate. Kinematic data was captured at 360 Hz by 14 cameras (Prime, OptiTrack, NaturalPoint Inc.; Corvallis, OR, USA), while kinetic data was simultaneously recorded at 1080 Hz via three force plates (Bertec Corp.; Columbus, OH, USA). Motion capture software (Motive 2.2–3.0; NaturalPoint Inc., Corvallis, OR, USA) synchronized both datasets. The force plates were embedded under the turf pitch surface (thickness = 0.013 m). One plate, positioned under the drive leg, captured data during the windup and stride phases. The other two plates, located in the pitcher's landing zone (1.3 m to 2.2 m in front of the rubber), collected data after stride leg landing. This landing zone plate was rotated ~4.8 degrees to align with the mound tilt. Pitch velocity was measured using a calibrated radar gun (Stalker Pro II; Stalker Sport; Richardson, TX, USA) placed behind the home plate, parallel to the pitch trajectory.

2.3 Data processing procedures

Kinematic and kinetic data underwent initial filtering in Visual3D (v6, professional, C-Motion, Germantown, MD, USA) using a fourth-order Butterworth low-pass filter, with respective cut-off frequencies of 20 Hz and 40 Hz [30]. A global coordinate system was established with the Z-axis vertical (positive upwards), the Y-axis oriented towards the home plate, and the X-axis perpendicular to the Y-Z plane.

The pelvis coordinate system utilized the CODA pelvis definition (Charnwood Dynamics Ltd., UK) within Visual3D. Hip joint centers were automatically calculated using previously published equations [33]. The trunk model adhered to International Society of Biomechanics (ISB) recommendations, with the shoulder joint center determined as an offset from the acromion markers, referencing Dr. George Rab's model (2002) [34, 35]. Joint centers for the ankle, knee, elbow, and wrist were defined as the midpoint between their respective medial and lateral markers.

Inverse dynamics (following Feltner and Dapena, 1989) was employed to calculate pitching arm joint forces and torques [36]. This approach estimates these parameters based on joint kinematics and the inertial properties of adjacent segments. Separate 7-degree-of-freedom (DOF) Inverse Kinematics (IK) models were constructed in Visual3D for each upper limb:

Shoulder: 3 DOF (horizontal adduction/abduction, adduction/abduction, internal/external rotation).

Elbow: 2 DOF (flexion/extension, supination/pronation).

Wrist: 2 DOF (flexion/extension, ulnar/radial flexion).

The pitching motion was segmented into 3 phases [8] (see

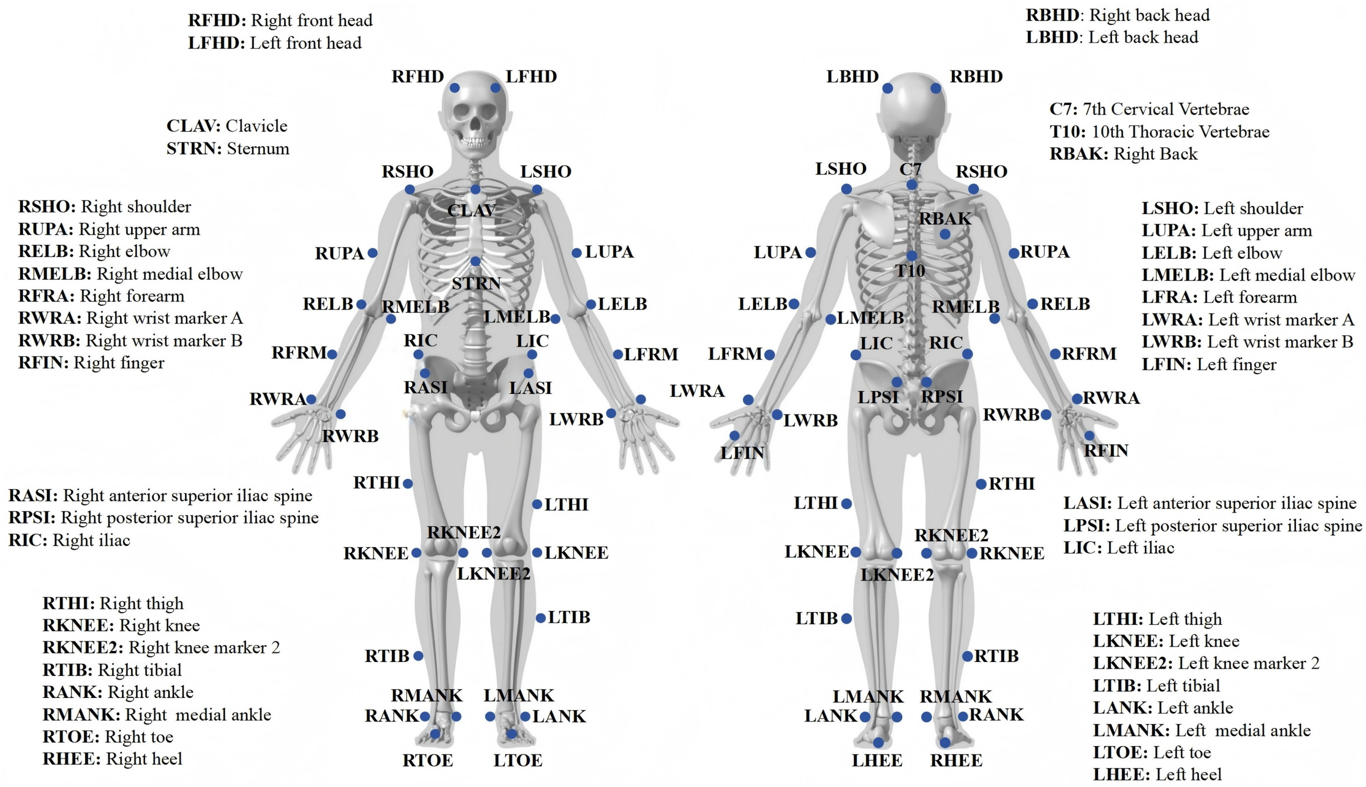

FIGURE 1. Marker set.

Fig. 2):

1. Stride Phase: From Maximum Knee Height (MKH) to Stride Foot Contact (SFC).

2. Arm Cocking Phase: SFC to Shoulder Maximum External Rotation (MER).

3. Arm Acceleration Phase: MER to Ball Release (BR).

Key event definitions:

SFC: Ground reaction force (GRF) exceeding 10 N vertically [20].

BR: Peak hand segment rotation within the global coordinate system [37]. This kinematic release point substitute metric was selected because it provides a stable method for determining the release instant based on motion capture technology, which has been employed in prior biomechanical studies of baseball pitching [37].

Shoulder IRT was normalized to body weight in Newtons multiplied by height in meters. Biomechanical efficiency was calculated as ball velocity per unit of normalized joint torque [29, 30]. Based on prior research, 29 kinematic parameters were calculated for the pitching phase (Table 1) [29, 30, 38, 39].

2.4 Statistical analyses

Shoulder biomechanical efficiency was assessed using a series of statistical analyses. The dual analytical approach was employed to address different research questions. Multiple regression identified the complete set of kinematic variables that collectively predict shoulder IRT efficiency across the continuous spectrum of pitching performance. The supplementary extreme group comparison (upper and lower 33%) was conducted to identify which of these predictors demonstrate the largest effect sizes and thus may represent the most promising targets for practical coaching interventions. First, Correlation analyses were performed on all variables and all possible uncorrelated combinations of variables of interest and shoulder joint IRT biomechanical efficiency were evaluated to derive the optimal set of parameters. Second, multiple regression was used to assess the relationship of the variables of interest with shoulder IRT biomechanical efficiency. Independence of the residuals was tested using the Durbin-Watson test, multicollinearity between the variables was tested using the Variance Inflation Factor (VIF), and the normal distribution of the residuals was verified using residual histograms to ensure that any traditional regression assumptions were not violated [40, 41]. Then, high and low biomechanical efficiency groups were formed based on the upper and lower 33% distributions of the biomechanical efficiency metrics as in previous studies [29]. Significant predictors of multiple regression, by Mann-Whitney U test, were compared between high and low biomechanical efficiency groups. All analyses were conducted using SPSS (version 26, IBM, Armonk, NY, USA) a priori, with $\alpha = 0.05$ considered for statistical significance.

3. Results

The residuals of the regression results satisfied normality, homogeneity of variance, and independence, and there was no multicollinearity between the respective variables. Multiple linear regression analysis showed that 6 kinematic variables explained 41.3% of the variance in shoulder IRT biomechanical efficiency (Table 2). Decreased elbow flexion angle, shoulder abduction angle, and horizontal abduction angle at the moment of SFC were associated with an increase in shoulder

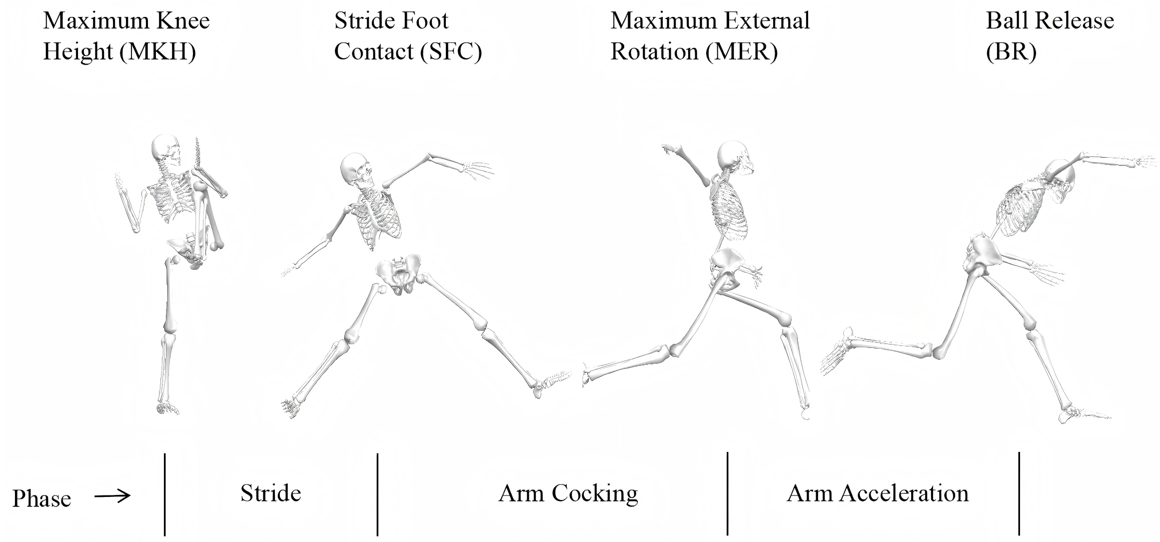

FIGURE 2. Phase division.

TABLE 1. 29 kinematic variables were identified based on previous studies.

Categorization	Number	Parameters (unit)
SFC		
	1	Step length (% height)
	2	Stride leg knee angle (°)
	3	Trunk longitudinal rotation angle (°)
	4	Pelvic rotation angle (°)
	5	Shoulder horizontal abduction angle (°)
	6	Shoulder abduction angle (°)
	7	Shoulder external rotation angle (°)
	8	Elbow flexion angle (°)
MER		
	9	Shoulder external rotation angle (°)
	10	Shoulder horizontal abduction angle (°)
	11	Shoulder abduction angle (°)
	12	Knee angle (°)
	13	Elbow flexion angle (°)
BR		
	14	Stride leg knee angle (°)
	15	Trunk forward flexion angle (°)
	16	Trunk contralateral tilt angle (°)
	17	Shoulder abduction angle (°)
SFC-BR		
	18	Max pelvis rotational angular velocity (MPAV) (°/s)
	19	Max pelvis rotational angular velocity (MTAV) (°/s)
	20	Relative trunk rotation velocity (%)
	21	Max shoulder horizontal adduction angular velocity (°/s)
	22	Max shoulder external rotation angular velocity (°/s)
	23	Max shoulder internal rotation angular velocity (°/s)
	24	Stride leg knee excursion angle (°)

TABLE 1. Continued.

Categorization	Number	Parameters (unit)
Time		
	25	SFC to MER (ms)
	26	SFC to MPAV (ms)
	27	SFC to Max trunk rotational angular velocity (MTAV) (ms)
	28	MPAV to MTAV (ms)
	29	Trunk rotation onset time (%PC)

SFC: stride foot contact; MER: maximum external rotation; BR: ball release; MPAV: maximum pelvis rotational angular velocity; MTAV: maximum trunk rotational angular velocity.

TABLE 2. Results of multiple linear regressions explaining variance in shoulder internal rotation torque biomechanical efficiency.

Parameter	Unstandardized coefficients	Standardized coefficients	p value
SFC elbow flexion angle (°)	−1.716	−0.351	0.002
SFC shoulder abduction angle (°)	−2.286	−0.254	0.025
Time MPAV to MTAV (ms)	−1.576	−0.298	0.005
SFC shoulder horizontal abduction angle (°)	−1.503	−0.230	0.034
MER shoulder external rotation angle (°)	2.863	0.312	0.006
MER knee angle (°)	1.727	0.023	0.049

$R = 0.642$, $R^2 = 0.413$. SFC: stride foot contact; MER: maximum external rotation; MPAV: maximum pelvis rotational angular velocity; MTAV: maximum trunk rotational angular velocity.

IRT biomechanical efficiency. Increasing shoulder external rotation angle and knee flexion angle at the moment of MER was associated with increased shoulder IRT biomechanical efficiency. In terms of temporal variables, reducing the maximum pelvis rotational angular velocity (MPAV) to maximum trunk rotational angular velocity (MTAV) time improved shoulder biomechanical efficiency.

The results of the Mann-Whitney U tests between the high and low efficiency groups showed no significant differences between height, weight, and ball speed (Table 3). However, the shoulder joint was subjected to a significantly greater IRT in the low efficiency group (0.075 ± 0.005 *vs.* 0.055 ± 0.004 (%wt $\times$ ht), $p < 0.001$). Among the kinematic variables, the shoulder abduction angle was significantly smaller at the SFC moment in the high efficiency group and had a significantly larger shoulder external rotation angle at the MER moment. No significant differences were found for the other four predictors identified in the regression analysis (SFC elbow flexion angle, Time MPAV to MTAV, SFC shoulder horizontal abduction angle, and MER knee angle).

4. Discussion

The internal rotation torque (IRT) exerted on the shoulder joint during pitching is considered to be a potential contributor to shoulder injuries because the load is associated with rotator cuff and glenoid labral pathology [6–9]. However, load is also related to pitching velocity, and biomechanical efficiency has often been used by researchers in recent years to better assess baseball pitching technique [29, 42]. Evaluating the relationship between pitching mechanics and shoulder joint biomechanical efficiency can maximize pitching velocity and theoretically minimize injury risk by reducing shoulder loading. Our study found that 6 kinematic parameters explained 41.3% of the variance in shoulder IRT biomechanical efficiency. Although regression analyses cannot determine whether shoulder biomechanical efficiency is directly determined by these factors, the probability of prediction based on these parameters is high. Our findings also reinforce previously published papers related to shoulder loading [22, 35].

It is noteworthy that while multiple regression identified six kinematic variables as significant predictors of shoulder IRT efficiency, only two of these (shoulder abduction angle at SFC and shoulder external rotation at MER) demonstrated significant differences in the extreme group comparison. This discrepancy may reflect the different sensitivities of these analytical approaches: regression models capture continuous relationships across the full data spectrum, whereas group comparisons highlight the most pronounced differences between biomechanical extremes. The four variables that were significant in regression but not in group comparisons (SFC elbow flexion, SFC shoulder horizontal abduction, Time MPAV to MTAV, and MER knee angle) may represent subtler modulators of efficiency that, while statistically relevant, do not reach the threshold of practical significance for distinguishing between high and low-efficiency performers. This distinction is valuable for prioritizing coaching interventions, suggesting that modifying shoulder abduction and external rotation angles may yield the most immediate improvements in efficiency.

The 3 kinematic parameters contributing to shoulder IRT biomechanical efficiency occur early in pitching (*i.e.*, SFC)

TABLE 3. Comparison of parameters between high and low efficiency groups.

Parameter	Low Efficiency (n = 22)	High Efficiency (n = 22)	p value
Height (m)	1.83 ± 0.06	1.86 ± 0.07	0.169
Mass (kg)	87.36 ± 7.86	88.18 ± 11.44	0.839
Ball velocity (m/s)	38.04 ± 1.84	38.01 ± 1.87	0.921
Normalized shoulder internal rotation torque (%wt × ht)	0.075 ± 0.005	0.055 ± 0.004	<0.001*
Pitching efficiency ($m \cdot s^{-1}$/%wt × ht)	510.8 ± 27.19	701.0 ± 63.47	<0.001*
SFC elbow flexion angle (°)	102.4 ± 16.03	96.45 ± 20.35	0.268
SFC shoulder abduction angle (°)	89.19 ± 8.75	83.87 ± 6.7	0.022*
Time MPAV to MTAV (ms)	14.82 ± 18.46	6.82 ± 9.82	0.126
SFC shoulder horizontal abduction angle (°)	45.06 ± 12.44	38.91 ± 15.60	0.229
MER shoulder external rotation angle (°)	165.2 ± 9.50	171.3 ± 8.33	0.027*
MER knee angle (°)	47.72 ± 9.69	51.99 ± 14.29	0.137

*Data are shown as mean ± SD. SFC: stride foot contact; MER: maximum external rotation; MPAV: maximum pelvis rotational angular velocity; MPTV: maximum trunk rotational angular velocity. *p < 0.05.*

and have been shown to be modifiable after coaching instruction rather than instruction aimed at modifying the later portion of the motion in pitching. Previous studies have found that a decrease in shoulder abduction angle during SFC is associated with elbow biomechanical efficiency, and our study had a similar finding, *i.e.*, decreasing shoulder abduction angle at SFC similarly improves shoulder IRT biomechanical efficiency [29, 43]. The average shoulder abduction angle in the high efficiency group was 83 degrees (Table 3), and considering previous studies, we believe that the shoulder abduction angle should be maintained at around 85º at the SFC to minimize the shoulder IRT load, though coaches should consider potential trade-offs with other aspects of the kinetic chain when implementing this adjustment [29, 44]. Furthermore, decreasing the horizontal abduction angle of the shoulder joint during SFC was also associated with increased shoulder IRT biomechanical efficiency. A larger horizontal abduction angle of the shoulder joint during SFC means that the shoulder is located further behind the pitcher which increases the stretching of the internal rotators of the shoulder resulting in the emergence of a greater IRT [45].

The elbow flexion angle at SFC is closely related to elbow loading, while a more flexed elbow angle changes the position of the centre of mass of the entire arm, increasing the rotational inertia of the shoulder joint for internal and external rotation, and subjecting the shoulder to a greater internal rotation moment driven by torque rotation of the torso. However, the increased internal rotation moment does not appear to be fully converted to ball velocity, resulting in a reduction in biomechanical efficiency [39]. While this variable was a significant predictor in the regression model, it did not differ significantly between the extreme efficiency groups, suggesting its effect may be more subtle compared with the primary factors of shoulder abduction and external rotation.

An increase in shoulder external rotation angle at MER was associated with an increase in shoulder IRT biomechanical efficiency. Although increasing shoulder external rotation during MER simultaneously increases elbow biomechanical efficiency, excessive shoulder external rotation is also detrimental because it can lead to laxity of the anterior capsule membrane and internal impingement of the shoulder joint [46, 47]. Therefore, coaches should emphasize achieving increased external rotation through controlled mobility and stability, rather than promoting excessive ranges that may compromise joint integrity.

Improvements in shoulder IRT biomechanical efficiency were also associated with a reduction in the time between MPAV and MTAV, and a previous study demonstrated that increasing the time from SFC to MPAV reduced shoulder IRT [23]. Consequently, an extended time from SFC to MPAV may allow for better energy accumulation, which in turn enables a more rapid trunk rotation (shorter MPAV to MTAV time). This optimized timing ensures that the larger muscle groups of the core and lower body contribute more effectively to the pitch, lessening the reliance on the shoulder musculature and thus improving overall shoulder biomechanical efficiency.

In addition, a more flexed knee angle at MER was associated with increased shoulder biomechanical efficiency. This relationship can be understood through the "joint-by-joint" approach to athletic movement, which posits that proper sequencing and positioning in distal joints (*e.g.*, knee) directly influence loading patterns in proximal joints (*e.g.*, shoulder) through the kinetic chain [44]. Although numerous studies have found a correlation between lower extremity flexion angle and ball velocity, the relationship between lower extremity flexion angle and shoulder IRT is still lacking [48]. Future studies are necessary to examine the relationship between knee flexion angle and extension velocity and shoulder loading throughout the SFC to BR phase.

The practical implementation of these findings can be guided by recent applied research demonstrating that targeted training interventions can effectively modify shoulder function in throwing athletes [49]. Specifically, exercises that promote proper shoulder positioning at SFC and controlled external rotation at MER, combined with drills that optimize the timing between pelvic and trunk rotation, may help pitchers achieve the kinematic patterns associated with improved efficiency while maintaining joint health.

5. Limitations

A main limitation of this study is that the experimental data originates from a baseball pitching database, and as the data collection predates 2022, it may not be sufficiently recent. Furthermore, no preliminary assessment of the required sample size was conducted. Although the pitchers were sufficiently warmed up to acclimatize to the experimental environment prior to the experiment, the data collected in the laboratory would have affected the pitchers' performance. Due to the complexity of the pitching mechanism, it is still unknown whether our findings can be generalized to other levels of pitchers, and therefore, caution should be exercised when generalizing to youth or professional pitchers.

6. Conclusions

This study successfully explored the relationship between pitching kinematics and shoulder internal rotation torque biomechanical efficiency. Multiple regression analysis identified six kinematic parameters that collectively explained 41.3% of the variance in efficiency, including SFC elbow flexion angle, SFC shoulder abduction angle, time from MPAV to MTAV, SFC shoulder horizontal abduction angle, MER shoulder external rotation angle, and MER knee angle. Furthermore, by comparing high- and low-efficiency groups, we confirmed that a reduced shoulder abduction angle at SFC and an increased shoulder external rotation angle at MER were the most pronounced factors distinguishing the efficiency extremes. These results underscore the potential for improving pitching biomechanics through targeted training of these modifiable kinematic parameters.

ABBREVIATIONS

IRT, internal rotation torque; MKH, maximum knee height; SFC, stride foot contact; MER, maximum external rotation; BR, ball release; GRF, ground reaction force; MPAV, maximum pelvis rotational angular velocity; MTAV, maximum trunk rotational angular velocity; DOF, degree-of-freedom; IK, Inverse Kinematics; VIF, Variance Inflation Factor; ISB, International Societyof Biomechanics.

AVAILABILITY OF DATA AND MATERIALS

Dataset Address: https://github.com/drivelineresearch/openbiomechanics.

AUTHOR CONTRIBUTIONS

MLD, XTG and SK—designed the research study. MLD, XTG, SW and NW—performed the research. HH, NW and SK—provided help and advice on design, experimental set-up, interpretation, and resources. MLD, XTG, SW and HH—analyzed the data. MLD, XTG, HH and SK—wrote and revise the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All data originate from Wasserberger's OpenBiomechanics Project database and that informed consent was not required, the Western IRB provided ethical approval for all data collection procedures (Western IRB #WB-DLR-115).

ACKNOWLEDGMENT

We extend our gratitude to Wasserberger and his colleagues for their contributions to The OpenBiomechanics Project, whose elite baseball database served as the data source for this study.

FUNDING

This research received no external funding.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Posner M, Cameron KL, Wolf JM, Belmont PJ III, Owens BD. Epidemiology of major league baseball injuries. The American Journal of Sports Medicine. 2011; 39: 1676–1680.

[2] McFarland EG, Wasik M. Epidemiology of collegiate baseball injuries. Clinical Journal of Sport Medicine. 1998; 8: 10–13.

[3] Li X, Zhou H, Williams P, Steele JJ, Nguyen J, Jäger M, *et al*. The epidemiology of single season musculoskeletal injuries in professional baseball. Orthopedic Reviews. 2013; 5: e3.

[4] Collins CL, Comstock RD. Epidemiological features of high school baseball injuries in the United States, 2005–2007. Pediatrics. 2008; 121: 1181–1187.

[5] Boltz AJ, Powell JR, Robison HJ, Morris SN, Collins CL, Chandran A. Epidemiology of injuries in national collegiate athletic association men's baseball: 2014–2015 through 2018–2019. Journal of Athletic Training. 2021; 56: 742–749.

[6] Feltner M, Dapena J. Dynamics of the shoulder and elbow joints of the throwing arm during a baseball pitch. International Journal of Sport Biomechanics. 1986; 2: 235–259.

[7] McLeod WD, Andrews JR. Mechanisms of shoulder injuries. Physical Therapy. 1986; 66: 1901–1904.

[8] Fleisig GS, Escamilla RF, Andrews JR, Matsuo T, Satterwhite Y, Barrentine SW. Kinematic and kinetic comparison between baseball pitching and football passing. Journal of Applied Biomechanics. 1996; 12: 207–224.

[9] Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. The American Journal of Sports Medicine. 1995; 23: 233–239.

[10] Calabrese GJ. Pitching mechanics, revisited. International Journal of Sports Physical Therapy. 2013; 8: 652–660.

[11] Seroyer ST, Nho SJ, Bach BR, Bush-Joseph CA, Nicholson GP, Romeo AA. The kinetic chain in overhand pitching: its potential role for performance enhancement and injury prevention. Sports Health. 2010; 2: 135–146.

[12] Serrien B, Baeyens JP. The proximal-to-distal sequence in upper-limb motions on multiple levels and time scales. Human Movement Science. 2017; 55: 156–171.

[13] Chu SK, Jayabalan P, Kibler WB, Press J. The kinetic chain revisited: new concepts on throwing mechanics and injury. PM&R. 2016; 8: S69–S77.
[14] Werner SL, Gill TJ, Murray TA, Cook TD, Hawkins RJ. Relationships between throwing mechanics and shoulder distraction in professional baseball pitchers. The American Journal of Sports Medicine. 2001; 29: 354–358.
[15] Hutchinson MR, Ireland ML. Overuse and throwing injuries in the skeletally immature athlete. Instructional Course Lectures. 2003; 52: 25–36.
[16] Dhahbi W. Editorial: advancing biomechanics: enhancing sports performance, mitigating injury risks, and optimizing athlete rehabilitation. Frontiers in Sports and Active Living. 2025; 7: 1556024.
[17] Souaifi M, Dhahbi W, Jebabli N, Ceylan Hİ, Boujabli M, Muntean RI, *et al*. Artificial intelligence in sports biomechanics: a scoping review on wearable technology, motion analysis, and injury prevention. Bioengineering. 2025; 12: 887.
[18] Aguinaldo AL, Buttermore J, Chambers H. Effects of upper trunk rotation on shoulder joint torque among baseball pitchers of various levels. Journal of Applied Biomechanics. 2007; 23: 42–51.
[19] Wight J, Richards J, Hall S. Influence of pelvis rotation styles on baseball pitching mechanics. Sports Biomechanics. 2004; 3: 67–83.
[20] Oyama S, Yu B, Blackburn JT, Padua DA, Li L, Myers JB. Effect of excessive contralateral trunk tilt on pitching biomechanics and performance in high school baseball pitchers. The American Journal of Sports Medicine. 2013; 41: 2430–2438.
[21] Solomito MJ, Garibay EJ, Woods JR, Õunpuu S, Nissen CW. Lateral trunk lean in pitchers affects both ball velocity and upper extremity joint moments. The American Journal of Sports Medicine. 2015; 43: 1235–1240.
[22] Davis JT, Limpisvasti O, Fluhme D, Mohr KJ, Yocum LA, Elattrache NS, *et al*. The effect of pitching biomechanics on the upper extremity in youth and adolescent baseball pitchers. The American Journal of Sports Medicine. 2009; 37: 1484–1891.
[23] Urbin MA, Fleisig GS, Abebe A, Andrews JR. Associations between timing in the baseball pitch and shoulder kinetics, elbow kinetics, and ball speed. The American Journal of Sports Medicine. 2013; 41: 336–342.
[24] Manzi JE, Dowling B, Wang Z, Kunze KN, Estrada J, Fu MC, *et al.* Association of pitch timing and throwing arm kinetics in high school and professional pitchers. The American Journal of Sports Medicine. 2021; 49: 3386–3394.
[25] Solomito MJ, Garibay EJ, Cohen A, Nissen CW. Lead knee flexion angle is associated with both ball velocity and upper extremity joint moments in collegiate baseball pitchers. Sports Biomechanics. 2024; 23: 2626–2636.
[26] Solomito MJ, Cohen AD, Garibay EJ. Influence of stride length on upper extremity joint moments and ball velocity in collegiate baseball pitchers. Sports Biomechanics. 2023; 22: 1460–1469.
[27] Dowling B, Manzi JE, Raab G, Coladonato C, Dines JS, Fleisig GS. The relationship among lead knee extension, fastball velocity and elbow torque in professional baseball pitchers. Sports Biomechanics. 2024; 23: 2664–2674.
[28] Fleisig GS, Diffendaffer AZ, Ivey B, Aune KT. Do baseball pitchers improve mechanics after biomechanical evaluations? Sports Biomechanics. 2018; 17: 314–321.
[29] Crotin RL, Slowik JS, Brewer G, Cain EL III, Fleisig GS. Determinants of biomechanical efficiency in collegiate and professional baseball pitchers. The American Journal of Sports Medicine. 2022; 50: 3374–3380.
[30] Dong M, Li M, Qu Q, Kim Y, Kim S. Arm slot angles affect elbow and shoulder joint torque in elite college pitchers. Sports Biomechanics. 2025; 24: 2166–2183.
[31] Wasserberger KW BA, Besky DM, Jones BR, Boddy KJ. The OpenBiomechanics Project: the open source initiative for anonymized, elite-level athletic motion capture data. 2022. Available at: https://www.openbiomechanics.org/ (Accessed: 15 November 2022).
[32] Wasserberger KW, Giordano KA. Ground reaction forces in baseball pitching: temporal associations with pitch velocity among high-velocity pitchers. Sports Biomechanics. 2025; 24: 1464–1478.
[33] Bell AL, Pedersen DR, Brand RA. A comparison of the accuracy of several hip center location prediction methods. Journal of Biomechanics. 1990; 23: 617–621.
[34] Wu G, van der Helm FC, Veeger HE, Makhsous M, Van Roy P, Anglin C, *et al*. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand. Journal of Biomechanics. 2005; 38: 981–992.
[35] Rab G, Petuskey K, Bagley A. A method for determination of upper extremity kinematics. Gait & Posture. 2002; 15: 113–119.
[36] Feltner ME, Dapena J. Three-dimensional interactions in a two-segment kinetic chain. Part I: general model. International Journal of Sport Biomechanics. 1989; 5: 403–419.
[37] Wasserberger KW, Giordano KA, de Swart A, Barfield JW, Oliver GD. Energy generation, absorption, and transfer at the shoulder and elbow in youth baseball pitchers. Sports Biomechanics. 2024; 23: 1160–1175.
[38] Milewski MD, Õunpuu S, Solomito M, Westwell M, Nissen CW. Adolescent baseball pitching technique: lower extremity biomechanical analysis. Journal of Applied Biomechanics. 2012; 28: 491–501.
[39] Aguinaldo AL, Chambers H. Correlation of throwing mechanics with elbow valgus load in adult baseball pitchers. The American Journal of Sports Medicine. 2009; 37: 2043–2048.
[40] Durbin J, Watson GS. Testing for serial correlation in least squares regression: I. Biometrika. 1950; 37: 409–428.
[41] Hastie T, Tibshirani R, Friedman J. An introduction to statistical learning. Springer: New York. 2009.
[42] Post EG, Laudner KG, McLoda TA, Wong R, Meister K. Correlation of shoulder and elbow kinetics with ball velocity in collegiate baseball pitchers. Journal of Athletic Training. 2015; 50: 629–633.
[43] Werner SL, Murray TA, Hawkins RJ, Gill TJ. Relationship between throwing mechanics and elbow valgus in professional baseball pitchers. Journal of Shoulder and Elbow Surgery. 2002; 11: 151–155.
[44] Dhahbi W, Materne O, Chamari K. Rethinking knee injury prevention strategies: joint-by-joint training approach paradigm versus traditional focused knee strengthening. Biology of Sport. 2025; 42: 59–65.
[45] Takagi Y, Oi T, Tanaka H, Inui H, Fujioka H, Tanaka J, *et al*. Increased horizontal shoulder abduction is associated with an increase in shoulder joint load in baseball pitching. Journal of Shoulder and Elbow Surgery. 2014; 23: 1757–1762.
[46] Mihata T, Lee Y, McGarry MH, Abe M, Lee TQ. Excessive humeral external rotation results in increased shoulder laxity. The American Journal of Sports Medicine. 2004; 32: 1278–1285.
[47] Jobe CM. Posterior superior glenoid impingement: expanded spectrum. Arthroscopy. 1995; 11: 530–536.
[48] Manzi JE, Yu JS, Sudah SY, Wishman M, Quan T, Koo A, *et al.* A systematic review of lower-body kinematic and strength factors associated with pitch velocity in adult baseball pitchers. Journal of Sport Rehabilitation. 2023; 32: 440–448.
[49] Agrebi B, Dhahbi W, Abidi H, Kasmi S, Houas N, Chtara M, *et al*. Isokinetic peak torque improvement and shoulder muscle ratios imbalance correction after specific strength training on a new ballistic throwing device: a randomized controlled trial. Journal of Sport Rehabilitation. 2024; 33: 423–436.

How to cite this article: Maolin Dong, Xiaotao Guo, Nan Wang, Shuai Wang, Hao Hong, Sukwon Kim. Kinematic predictors of shoulder torque efficiency: implications for injury risk in collegiate baseball pitchers. Journal of Men's Health. 2026; 22(3): 49-56. doi: 10.22514/jomh.2026.026.