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Hip Flexibility and Pitching Biomechanics in Adolescent Baseball Pitchers

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Context: Inadequate hip active range of motion (AROM) may stifle the energy flow through the kinematic chain and decrease pitching performance while increasing the risk for pitcher injury.

Objective: To examine the relationship between hip AROM and pitching biomechanics during a fastball pitch in adolescent baseball pitchers.

Design: Cross-sectional study.

Setting: Biomechanics laboratory.

Patients or Other Participants: A sample of 21 adolescent male baseball pitchers (age = 16.1 ± 0.8 years, height = 183.9 ± 5.2 cm, mass = 77.9 ± 8.3 kg).

Main Outcome Measure(s): Bilateral hip external-rotation (ER), internal-rotation, flexion, abduction, and extension AROM were measured. Three-dimensional biomechanics were assessed as participants threw from an indoor pitching mound to a strike-zone net at regulation distance. Pearson product moment correlation coefficients were used to determine relationships between hip AROM and biomechanical metrics.

Results: Negative correlations were found at foot contact between back-hip ER AROM and torso-rotation angle ($r = -0.468$, $P = .03$), back-hip ER AROM and back-hip abduction angle ($r = -0.474$, $P = .03$), and back-hip abduction AROM and lead-hip abduction angle ($r = -0.458$, $P = .04$). Back-hip extension AROM was positively correlated with increased stride length ($r = 0.446$, $P = .043$). Lead-hip abduction AROM was also positively correlated with normalized elbow-varus torque ($r = 0.464$, $P = .03$).

Conclusions: We observed several relationships between hip AROM and biomechanical variables during the pitching motion. These findings support the influence that hip AROM can have on pitching biomechanics. Overall, greater movement at the hips allows the kinematic chain to work at maximal efficiency, increasing the pitch velocity potential.

Key Words: active range of motion, kinematic chain, elbow torque, injury prevention

Key Points

- Clinically measured hip active range of motion was correlated with pitching kinematics at foot contact in adolescent pitchers.
- Hip active range of motion was also positively correlated with normalized peak elbow-varus torque during pitching.

In baseball, the pitcher's ability to remain healthy while repeatedly throwing a high-speed pitch is an integral part of the season. Pitching is a dynamic task that creates motions that are stressful on and unnatural for the upper extremity and generates high levels of force that are not normally reached in joints.[1] As a result of this repetitive motion, shoulder and elbow injuries are well-recognized problems in baseball pitchers.[2–4] Researchers have shown that continuous medial elbow-valgus overloading during the throwing motion can lead to ulnar collateral ligament injury[5] and that ulnar collateral ligament injuries have steadily increased across all levels of athletes.[6,7] Erickson et al[7] found that the number of 15- to 19-year-old US players undergoing ulnar collateral ligament reconstructive surgery increased by 9.12% per year between 2007 and 2011.

Investigators[8] have demonstrated that the kinematic chain in pitching begins in the lower extremities and transitions to the upper extremity. The mechanics of the lower extremities are recognized as a crucial part of the pitching motion, and these contributions have been described as necessary for moving the upper extremity joints into appropriate and safe positions to minimize the loads on various joints.[9] The lower extremities ultimately provide the foundation for the upper extremity throwing motion. A key component to the smooth transition of energy generated in the lower extremity is at the anatomical level of the hips.[10,11] Insufficient hip range of motion (ROM) can arrest throwing mechanics, thereby reducing energy transfer between the lower and upper extremities.[12–14] Pitchers who are able to more efficiently transfer energy up the chain will create greater forces in the upper extremity, which may result in greater ball velocity.[15] However, improper throwing mechanics can cause these forces to surpass the physiological thresholds of the shoulder and elbow joints, potentially causing injury.[5] Laudner et al[16] suggested that pitchers who lack appropriate mechanics may accommodate by placing a greater emphasis on upper extremity force generation alone, minimizing the role of the lower extremities. Researchers[10] have observed correlations between lower extremity ROM and various pitching biomechanical factors of the trunk and pelvis during the pitching motion. The ability to identify the hip-flexibility metrics associated with increased stresses on the throwing arm may help us characterize the injury risk in baseball pitchers.

Whereas the authors[9,10,17] of several studies examined pitching biomechanics and others[13,18,19] assessed hip passive ROM (PROM) in pitchers, to our knowledge, no one has evaluated associations between pitching biomechanics and hip active ROM (AROM) in adolescent pitchers. Saito et al[20] found associations between hip ROM and baseball players with or without throwing-elbow pain but did not explore pitching mechanics. Determining correlations between hip-flexibility measures and throwing-arm biomechanics during the pitching motion would allow a better understanding of the influence the hips have on the loads created in the shoulder and elbow joints. Therefore, the purpose of our study was to identify correlations between clinical hip AROM measurements and pitching biomechanics. We hypothesized that the kinematics at foot contact, specifically at the hips, would be correlated with lead- and back-hip AROM. We also hypothesized that peak elbow-varus torque (EVT) and peak shoulder internal-rotation (IR) torque would be correlated with lead- and back-hip AROM.

METHODS

Participants

A total of 21 adolescent male baseball pitchers (age = 16.1 ± 0.8 years, height = 183.9 ± 5.2 cm, mass = 77.9 ± 8.3 kg) from a local competitive youth baseball program participated in this study. Each pitcher had at least 4 years of pitching experience. No pitcher had current throwing-arm pain or a history of throwing-arm surgery. Participants underwent a single testing session involving clinical and biomechanical analyses. The study was performed during the preseason after the players had been throwing and pitching for several weeks. All participants and their parents provided written informed assent and consent, respectively, and the Institutional Review Board at the Medical College of Wisconsin approved the study.

Clinical Analysis

All pitchers performed an approximately 20-minute warm-up that focused on the whole body, using static and dynamic stretching and pitching drills. Static stretches of the lower extremities included the hamstrings, quadriceps, hip adductors, and hip external rotators; trunk static stretching was done by performing lunges with rotation, flexion, and extension; and upper extremity static stretching included posterior capsule and latissimus dorsi stretching. They followed up with dynamic stretching of the lower extremities by performing A skips, B skips, butt kicks, skipping with hip external rotation (ER) and IR, dynamic hamstrings stretching, and light sprints; dynamic upper extremity stretching was done using arm circles. Finally, they performed throwing drills focusing on different stages of the throwing cycle: stride, cocking stage to ball release, ball release, and follow-through drills.

After the warm-up, a single physical therapist (W.K.) collected AROM measurements. A goniometer (20 cm, 7540 EZ Read; Jamer) was used to collect AROM measurements at each hip, labeled as the *lead leg* or *back leg* depending on arm dominance. *Arm dominance* was defined as the arm used for pitching. A coin flip was used to randomly begin AROM testing with either the lead or back leg. Each pitcher's hip AROM was assessed in the same order: ER, IR, flexion, abduction, and extension. We performed AROM rather than PROM measurements. Researchers[21,22] have found hip end feel to be unreliable, which makes obtaining a valid result using PROM more difficult. According to a systematic review by van Trijffel et al,[23] interrater reliability for PROM at the hip was far less than for upper extremity measurements. For each measurement, 3 trials were recorded while the participant performed a 5-second active hold to ensure accurate measurement. The mean value of the 3 trials was used for data analysis.

Hip external and internal AROM was assessed with pitchers seated on the edge of a mat table with their hips and knees at a 90° angle. The goniometer axis was placed at the midpatella, with the stationary arm perpendicular to the floor and the movement arm parallel to the long axis of the tibia. To ensure that the stationary arm remained perpendicular to the floor, we kept it parallel to the mat table leg. First, pitchers were instructed to maximally externally rotate the hip while avoiding any compensatory hip-flexion movements or trunk flexion. Then we measured IR while the individual avoided any compensatory movement. Hip-flexion and -abduction AROM was measured with pitchers lying supine on the mat table. For hip flexion, the goniometer axis was placed at the greater trochanter, with the stationary arm parallel to the trunk and the movement arm parallel to the longitudinal axis of the femur in line with the lateral femoral epicondyle. With the knee flexed, pitchers were instructed to maximally flex the hip while avoiding any compensatory trunk flexion. For hip abduction, the goniometer axis was placed at the ipsilateral anterior-superior iliac spine (ASIS), with the stationary arm directed at the contralateral ASIS and the movement arm parallel to the femur, directed to the center of the patella. Pitchers were instructed to maximally abduct the hip while avoiding any compensatory movements, such as hip ER.

Hip-extension AROM was measured with pitchers lying prone on the mat table. The goniometer axis was placed at the greater trochanter, with the stationary arm parallel to the trunk and the movement arm parallel to the longitudinal axis of the femur in line with the lateral femoral condyle. With the knee fully extended, pitchers were instructed to maximally extend the hip while avoiding any compensatory trunk movement, such as lifting the ASIS off the mat. An assistant (not an author) placed the participant's forearm at the posterior-superior iliac spine level of the lumbar spine to avoid any compensation. The examiner was constantly monitoring whether the ASIS remained in contact with the table during measurement.

Biomechanical Analysis

A system of 8 Raptor-E cameras (Motion Analysis Corp) was positioned around an artificial pitching mound to capture the motion of pitchers at 300 frames per second.

Figure 1. Marker placement. A, Anterior view. B, Posterior view.

Forty-seven reflective markers (14-mm pearl; B&L Engineering) were attached to the participants at anatomical landmarks (Figure 1). After the 20-minute warm-up was completed and AROM measurements were collected, participants were allowed to throw to prepare for pitching as they normally would. When they were ready for the pitching assessment, we recorded a static trial with them on the mound and the arm at 90° of shoulder abduction, 90° of elbow flexion, and 90° of IR (palm parallel to the ground). We recorded 10 fastball pitches, with pitches thrown into a strike-zone net. Home plate was positioned at the regulation distance of 18.4 m from the pitching rubber. Velocity, pitch location, and spin rate of each pitch were recorded using the Pitching Monitor (model 2.0; Rapsodo LLC). The 3 fastest strikes were analyzed. Marker data were identified and filtered using a 13.4-Hz fourth-order Butterworth low-pass filter using Cortex software (Motion Analysis Corp), and kinematics and kinetics were calculated using a biomechanical model via Visual 3D software (C-Motion Inc).[24] Seventeen kinematic metrics were analyzed at foot contact: stride length; shoulder horizontal abduction; shoulder abduction; shoulder ER; elbow flexion; pelvic rotation; torso rotation; hip-to-shoulder separation; lead- and back-hip flexion, abduction, and ER; lead-knee flexion; and lead-foot position and angle. The 2 kinetic metrics analyzed were peak EVT and peak shoulder IR torque. These metrics are commonly reported in the pitching literature as having links to pitching injuries.[3,4,9,17,25] Torque was normalized by body mass (BM) and height (H)[26]:

$$\text{Normalized Torque} = \left[\frac{\text{Absolute Torque (N} \cdot \text{m)}}{\text{BM (N)} \cdot \text{H (m)}}\right] \times 100.$$

Statistical Analysis

Descriptive statistics including mean and SD were calculated for all variables. Scatterplots were examined for linearity to determine the appropriate correlation test. The associations were linear; thus, 2-tailed Pearson product moment correlation coefficients were used to examine associations between hip AROM measurements and biomechanical metrics. Correlations were assessed as *weak* ($0.1 < r < 0.3$), *moderate* ($0.3 < r < 0.5$), or *strong* ($r > 0.5$). The α level was set at .05. We used SPSS statistical analysis software (version 26; IBM Corp) to analyze the data.

RESULTS

The 21 pitchers included in the study had a mean ± SD fastball velocity of 34.3 ± 1.7 m/s. Results of the biomechanical metrics analyzed are presented in Table 1. Five correlations were found between pitching biomechanics and hip flexibility (Table 2). All the correlations were moderate, and scatterplots demonstrating their relationship are detailed in Figure 2. Three negative correlations between kinematics at foot contact and back-hip AROM were identified: torso-rotation angle and back-hip ER AROM ($r = -0.468$, $P = .03$), back-hip abduction angle

Table 1. Biomechanics of Adolescent Baseball Players

Variable	Mean ± SD
Kinematics at foot contact	
Stride length, % of height	81.3 ± 4.1
Shoulder, °	
Horizontal abduction [a]	−37.6 ± 11.1
Abduction	83.7 ± 14.1
External rotation	21.5 ± 27.8
Elbow flexion, °	99.3 ± 14.1
Pelvic rotation, °[b]	−64.9 ± 12.6
Torso rotation, °[b]	−94.6 ± 12.4
Hip-to-shoulder separation angle, °	28.8 ± 5.9
Lead-hip, °	
Flexion	54.0 ± 12.5
Abduction [a]	−36.1 ± 7.9
External rotation [a]	−3.0 ± 13.8
Back-hip, °	
Flexion	5.3 ± 13.6
Abduction [a]	−30.7 ± 7.6
Internal rotation	11.0 ± 9.0
Lead-knee flexion, °	40.9 ± 5.3
Lead-foot position, cm[c]	1.4 ± 12.1
Lead-foot angle, °[c]	8.3 ± 9.2
Peak kinetics	
Normalized elbow-varus torque, % mass · height	4.11 ± 0.65
Normalized shoulder internal-rotation torque, % body mass · height	3.89 ± 0.66

[a] A negative value indicates that the angle metric is listed in negative degrees.
[b] A negative value indicates the segment (pelvis or torso) is rotated in a clockwise direction on a right-handed pitcher.
[c] A positive value indicates the foot is in a closed position. For a right-handed pitcher, the lead foot pointing toward the third-base side reflects a closed foot position; the lead foot pointing toward a right-handed batter reflects a closed lead-foot angle.

and back-hip ER AROM ($r = -0.474$, $P = .03$), and lead-hip abduction angle and back-hip abduction AROM ($r = -0.458$, $P = .04$). One positive correlation was present between stride length at foot contact and back-hip extension AROM ($r = 0.446$, $P = .043$). A positive correlation was also observed between normalized EVT and lead-hip abduction AROM ($r = 0.464$, $P = .03$). Full correlation results are provided in the Supplemental Table (available online at https://doi.org/10.4085/1062-6050-0103.21.S1).

DISCUSSION

The proper use and transition of energy through the kinematic chain is crucial to pitching efficiency. Davis et al[27] suggested that limited hip ROM can stifle the coordination of the kinematic chain and result in increased stresses on upper extremity joints, ultimately increasing the injury risk. We found that greater back-hip ER AROM was moderately inversely related to the torso-rotation angle at foot contact ($r = -0.468$, $P = .03$). The level of hip ER is an indicator of hip IR muscle length. Greater ER of the leg indicates greater length and flexibility of the IR muscles, which allows increased mobility. The increased ER is important, as it enables pitchers to use their torsional forces from the lower extremity rather than the torso and upper extremity alone. An increase in hip ER AROM may spare the torso from rotating prematurely during the pitching cycle, potentially allowing energy to move more appropriately through the torso in an efficient timing sequence.

Our data also demonstrated that more back-hip ER AROM was moderately related to a greater back-hip abduction angle at foot contact ($r = -0.474$, $P = .03$). This may support the interplay of using the back hip as both a rotational pivot point and a mechanism to push down on the mound via hip abduction. Creating an additional rotational point below the trunk may increase the energy pitchers are able to generate during the pitching cycle.[15] It is important to begin pelvic rotation before torso rotation, as this allows for appropriate transfer through the kinematic chain, reducing inappropriate forces on joints and increasing pitch velocity.[2] Luera et al[26] noted that professional pitchers, who on average have greater ball speed than amateur pitchers, displayed greater lower extremity and pelvic rotation, reinforcing our results highlighting the importance of hip flexibility in rotation. Our results also showed the importance of the muscles influencing hip abduction. Increased flexibility at the hip joint allows pitchers to further abduct the back leg, creating a greater stride length. Researchers[28,29] have identified associations between stride length and ball speed. Improvement in pitchers' hip flexibility may ultimately increase the opportunity to generate greater velocities via crucial back-leg abduction.

Stride length is a well-known and easily accessible biomechanical measure of pitching mechanics. According to Fry et al,[30] stride length increases with pitching experience, and investigators[28,29] determined that increased stride length was correlated with increased pitching velocity. Our results indicated that increased back-hip extension AROM was moderately correlated with increased stride length ($r = 0.446$, $P = .043$). Thus, back-hip extension may be more vital than hip abduction because of the transition of the plane of motion seen in the back hip. As the pitching motion progresses during the stride phase, back-leg rotation changes the plane from frontal to sagittal. Therefore, hip extension helps propel the body down the mound and toward the plate. These results emphasize the importance of proper maintenance of the hip-flexor and -extensor muscles. Pitchers presenting with lower back pain

Table 2. Correlations Between Pitching Biomechanics and Hip Active Range of Motion

Variable	*r* Value	*P* Value
Kinematics at foot contact		
Stride length and back-hip extension active range of motion	0.446	.043[a]
Torso-rotation angle and back-hip external-rotation active range of motion	−0.468	.03[a]
Back-hip abduction angle and back-hip external-rotation active range of motion	−0.474	.03[a]
Lead-hip abduction angle and back-hip abduction active range of motion	−0.458	.04[a]
Kinetics		
Normalized elbow-varus torque and lead-hip abduction active range of motion	0.464	.03[a]

[a] Indicates correlation ($P < .05$).

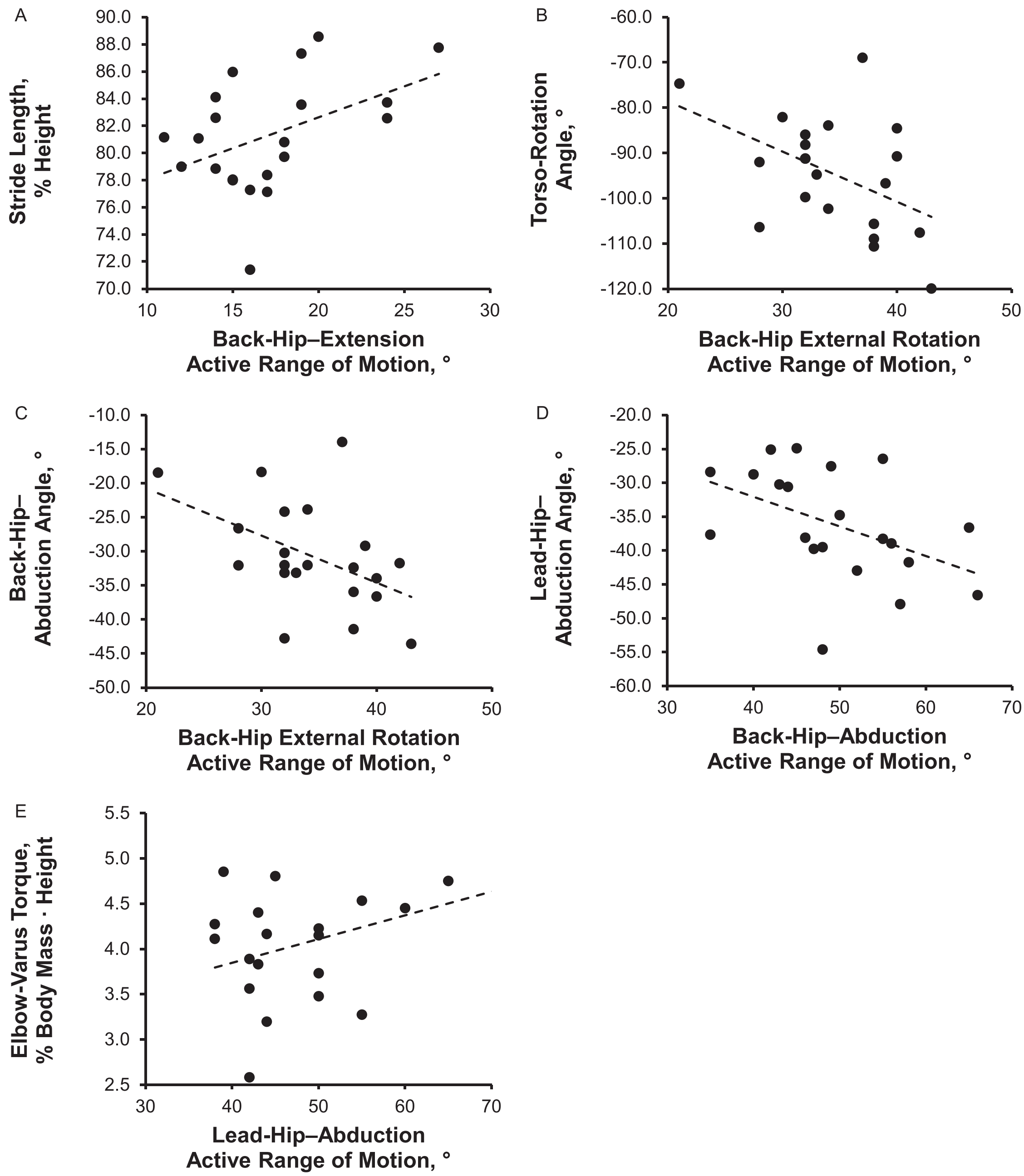

Figure 2. Scatterplots of correlations that were statistically significant. A, Stride length and back-hip–extension active range of motion (AROM; $R^2 = 0.199$, $P = .043$). B, Torso-rotation angle and back-hip–external-rotation AROM ($R^2 = 0.219$, $P = .03$). C, Back-hip–abduction angle and back-hip–external-rotation AROM ($R^2 = 0.225$, $P = .03$). D, Lead-hip–abduction angle and back-hip–abduction AROM ($R^2 = 0.210$, $P = .04$). E, Normalized elbow-varus torque and lead-hip–abduction AROM ($R^2 = 0.215$, $P = .03$).

due to psoas muscle injury or hip-joint dysfunction may have inflammation of the joint and surrounding musculature, resulting in tightness. As our findings demonstrated, this tightness may result in a decreased ability to extend the lower extremity, ultimately negatively affecting stride length and pitch velocity. Monitoring back-hip strength and flexibility may be useful for guiding pitchers toward a more powerful and sustainable throwing motion, potentially increasing the quality and longevity of their performance. These data also encourage a hip-centric training model, and coaches and sports medicine clinicians may monitor hip AROM measurements in consideration of injury prevention and rehabilitation.

Fortenbaugh et al[4] observed that an increase in EVT was correlated with an increase in pitch velocity. Our results revealed a connection between these points: a moderate positive correlation between lead-hip abduction AROM and normalized EVT ($r = 0.464$, $P = .03$). When the lead hip abducts, stride length increases, which, by increasing the efficiency of the kinematic chain, translates to increased energy reaching the distal upper extremity, generating a greater EVT.[17] Although greater elbow-varus forces have been correlated with increased pitch velocity, there are limits to how much force the ligaments surrounding the elbow joint can withstand before injury occurs.[1,5] These findings further support the influence of hip flexibility on the ability to throw a high-velocity pitch. In the future, researchers may uncover more and greater correlations between hip AROM and pitching biomechanics, potentially establishing hip-measurement goals for optimal pitching. Deficits discovered in hip AROM should be acknowledged and corrected in the prevention and rehabilitation of various upper extremity injuries common in adolescent pitchers. Future authors may also focus on how these measurements change when throwing pitches beyond fastballs or after throwing a number of pitches to note the influence of fatigue.

Our study had limitations. First, although we demonstrated the influence of hip AROM on biomechanics throughout the pitching motion, the hips are only 1 segment of the kinematic chain. Our results may be influenced by segments of the kinematic chain not examined during this study, which may alter the observed isolated findings on the hips. The development and use of a more involved linear model that focuses on hip AROM and specific biomechanical metrics may lead to a better explanation of the larger proportion of the variance in these metrics. Second, we used AROM as opposed to PROM testing when measuring pitchers' motion abilities. In most previous investigations, researchers evaluated PROM, which may mean that our results are not directly comparable with other research. Third, although we focused on the relationship the hips may have with pitcher-relevant clinical injuries, we cannot say that there is direct causation between hip AROM and upper extremity injury. Finally, the data were collected from a cohort of adolescent pitchers, which limits our ability to extrapolate to pitchers at the collegiate and professional levels.

CONCLUSIONS

Adolescent baseball pitchers who had greater back-hip–ER AROM during clinical measurements also displayed decreased back-hip abduction and torso-rotation angle at foot contact. Increased back-hip extension AROM also increased stride length while throwing. Increased lead-hip abduction AROM was correlated with increased normalized EVT. All the correlations were moderate. As such, our findings support the influence that hip AROM can have on pitching biomechanics. Greater movement at the hips allows the kinematic chain to work at maximal efficiency, increasing the pitch velocity potential and decreasing the risk for injury. Therefore, baseball pitchers should evaluate their hip AROM when training, and clinicians should consider measuring hip strength and flexibility to gain a clearer picture of players' pitching mechanics and injury risk potential.

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SUPPLEMENTAL MATERIAL

Supplemental Table. Found at DOI: https://doi.org/10.4085/1062-6050-0103.21.S1

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