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Hip Strength and Pitching Biomechanics in Adolescent Baseball Pitchers

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Context: Hip strength may influence the energy flow through the kinematic chain during baseball pitching, affecting athlete performance as well as the risk for injury.

Objective: To identify associations between hip strength and pitching biomechanics in adolescent baseball pitchers during 3 key events of the pitching cycle.

Design: Cross-sectional study.

Setting: Biomechanics laboratory.

Patients or Other Participants: A total of 26 adolescent male baseball pitchers (age = 16.1 ± 0.8 years, height = 184.29 ± 5.5 cm, mass = 77.5 ± 8.5 kg).

Main Outcome Measure(s): The main outcome measure was hip strength (external rotation, internal rotation, flexion, abduction, adduction, and extension). After strength measurements were acquired, motion capture was used to obtain a full-body biomechanical analysis at 3 events during the pitching cycle (foot contact, maximal external rotation, and ball release). We then evaluated these values for associations between hip strength and pitching biomechanics. Scatterplots were examined for linearity to identify an appropriate correlation test. The associations were linear; thus, 2-tailed Pearson correlation coefficients were used to determine correlations between biomechanical metrics. An α level of .01 was chosen.

Results: Ten strong correlations were found between pitching biomechanics and hip strength: 8 correlations between hip strength and kinematics at key points during the pitch and 2 correlations of hip strength with peak elbow-varus torque.

Conclusions: Several correlations were noted between lower extremity strength and pitching biomechanics. This information provides data that may be used to improve performance or reduce injury (or both) in pitchers. Increased hip strength in adolescent pitchers may both improve performance and decrease the risk of injury.

Key Words: kinematics, lower body strength, elbow torque, injury prevention

Key Points

- Clinically measured hip strength was correlated with pitching kinematics at key points during the pitching cycle in adolescent pitchers.
- Clinically measured hip strength was correlated positively with normalized peak elbow-varus torque during pitching in adolescent pitchers.

In baseball, researchers have shown that pitchers account for a larger proportion of injured players than other positions, and their injuries are more likely to need surgical intervention.[1] Pitching is a dynamic task that creates stressful and unnatural motions in the upper extremity, reaching levels of forces up to 5 times a pitcher's body weight.[2] Throughout the course of a pitcher's career, the repetitive throwing motion increases the risk for injury at the shoulder and elbow joints, which are well-recognized problems in baseball pitchers.[3–5] Continuous medial elbow valgus overloading during the throwing motion can lead to ulnar collateral ligament injury.[6] Investigators[4,5,7,8] have also observed that excessive shoulder internal-rotation torques can contribute to rotator cuff and other shoulder joint injuries. Because baseball pitching injuries continue to be prevalent, finding solutions to minimize the injury risk is increasingly important.

Pitching biomechanics have been associated with changes in both performance and susceptibility to injury.[9] Previous authors[10] found that a structured strengthening and stretching program reduced medial elbow injuries in youth baseball pitchers. Motion analysis and physical therapist evaluations have revealed correlations between hip flexibility and pitching biomechanics.[11] The pitching cycle has been described as a kinetic chain deriving energy from the lower extremities and transferring this energy via pelvic and trunk rotation to the upper extremities to produce throwing velocity.[12–14] Therefore, strengthening of the lower extremities, as the origin of the energy transferred to the throwing arm, has been hypothesized to enhance performance as well as avoid injury.[15] In a recent study, Yanagisawa et al[16] showed a positive association between both lead-hip and back-hip strength and increased pitching velocity. In addition, Laudner et al[17] discovered a relationship between lumbopelvic control of the drive leg and both shoulder horizontal torque and elbow-valgus torque (EVT) during the throwing motion. This demonstrates the importance of strengthening the musculature involved with lumbopelvic control in the lower extremities to help divert excessive upper extremity forces and reduce the risk of resulting injury.

The purpose of our study was to identify associations between hip strength and pitching biomechanics in adolescent baseball pitchers, to aid in filling the void of knowledge regarding relationships between these variables. Specifically, we hypothesized that correlations would exist between lead-leg and back-leg extension strength and upper extremity kinematics and kinetics. We also hypothesized that correlations would exist between peak EVT and peak shoulder internal-rotation torque with lead-hip and back-hip strength.

METHODS

Participants

Participants were 26 right-handed adolescent male baseball pitchers (age = 16.1 ± 0.8 years, height = 184.29 ± 5.5 cm, mass = 77.5 ± 8.5 kg) from a local competitive youth baseball program with at least 3 years of pitching experience and no current arm pain and no history of throwing-arm surgery. We defined *arm dominance* as the arm used for pitching. They underwent a clinical and a biomechanical analysis during 1 testing session performed during the preseason after they had been throwing and pitching for several weeks. The institutional review board of the Medical College of Wisconsin approved the project. All participants and their guardians provided written informed assent and consent, respectively.

Clinical Analysis

All pitchers performed an approximately 20-minute warm-up as described in a previous article.[11] The warm-up focused on the whole body by using static and dynamic stretching and pitching drills. After the warm-up, a single certified physical therapist (W.K.) collected all strength measurements. Strength was assessed for each hip, labeled as *lead leg* or *back leg* based on arm dominance. Because all pitchers were right handed, the lead leg was the left leg and the back leg was the right leg. A coin flip was performed to randomly begin strength testing with either the lead or back leg. Each pitcher's hip strength was measured in the following order: external rotators, internal rotators, flexors, abductors, adductors, and extensors. Our study followed established standardized test positions for measuring hip strength.[18] A MicroFET2 dynamometer (Hoggan Health Industries) was used to record isometric strength measurements. We administered make tests rather than break tests due to their higher reliability.[19] Three trials of a 5-second maximal voluntary isometric contraction were performed for each strength measurement. The mean value of the 3 trials was used for data analysis.

Hip external-rotator, internal-rotator, and flexor strength were measured with the pitchers seated on the edge of a mat table with their hips and knees at 90° angles. For the external rotators, the dynamometer was placed 5 cm proximal to the medial malleolus. The participants were instructed to maximally externally rotate the hip while avoiding any compensatory hip-flexion and trunk movements. For internal rotators, the dynamometer was placed 5 cm proximal to the lateral malleolus. The pitchers were instructed to maximally internally rotate the hip while avoiding any compensatory hip-flexion and trunk movements. For the hip flexors, the dynamometer was placed 5 cm proximal to the edge of the patella. Participants were instructed to maximally flex the hip while avoiding any compensatory movements, such as trunk backward or forward leaning.

Hip-abductor and hip-adductor strength was measured with the pitchers on the mat table in a side-lying position. The hips were stacked via the physical therapist's hand at the greater trochanter to ensure no trunk or pelvic rotation with the top leg lifted in a neutral position. For the hip abductors, the dynamometer was placed 5 cm above the lateral malleolus. Participants were instructed to maximally abduct the hip while avoiding any compensatory trunk rotation. For the hip adductors, the top leg was brought forward into hip flexion to allow the bottom leg to be lifted in adduction in a neutral position. The dynamometer was placed 5 cm above the medial malleolus. The pitchers were instructed to maximally adduct the hip while avoiding any compensatory trunk rotation.

Hip-extensor strength was measured with the pitcher lying prone on a treatment table. The dynamometer was placed posteriorly, 5 cm above the medial malleolus. Participants were instructed to maximally extend the hip while avoiding any compensatory pelvic lift of the anterior-superior iliac spine and trunk extension. Repeatability of dynamometer measures was excellent, with intraclass correlation coefficient (ICC) values ranging from 0.896 to 0.971.

Biomechanical Analysis

Biomechanical analysis was conducted similarly to that in an earlier study.[11] Reflective markers were attached at anatomical landmarks as shown in Figure 1. After the 20-minute warm-up was completed and strength measurements were collected, the pitchers threw to prepare for pitching as they normally would. When they were ready for the pitching assessment, we recorded a static trial as previously described.[11] Velocity and pitch location of each pitch were recorded using Pitching Monitor (model 2.0; Rapsodo LLC). We calculated all kinematics and kinetics using a biomechanical model in Visual 3D software (C-Motion, Inc).[20] Thirteen kinematic metrics were analyzed at foot contact, maximal shoulder external rotation (MER), and ball release (BR; Figure 2), consisting of shoulder external rotation, horizontal abduction, and abduction; elbow flexion; pelvic rotation; torso rotation; hip-to-shoulder separation; and lead-hip and back-hip external rotation, flexion, and abduction. As in a previous study,[11] we analyzed 2 kinetic metrics: peak EVT and peak shoulder internal-rotation torque. These metrics are commonly reported in the pitching literature with links to pitching injuries.[4,5,7,8,21] Torque was normalized by body mass and height as described in another study.[11,22]

Statistical Analysis

Descriptive statistics including means and SDs were calculated for all variables. Scatterplots were examined for linearity to identify the appropriate correlation test. The Shapiro-Wilk test confirmed that the data were normally distributed. The associations were linear, so we used 2-tailed Pearson correlation coefficients to examine associa-

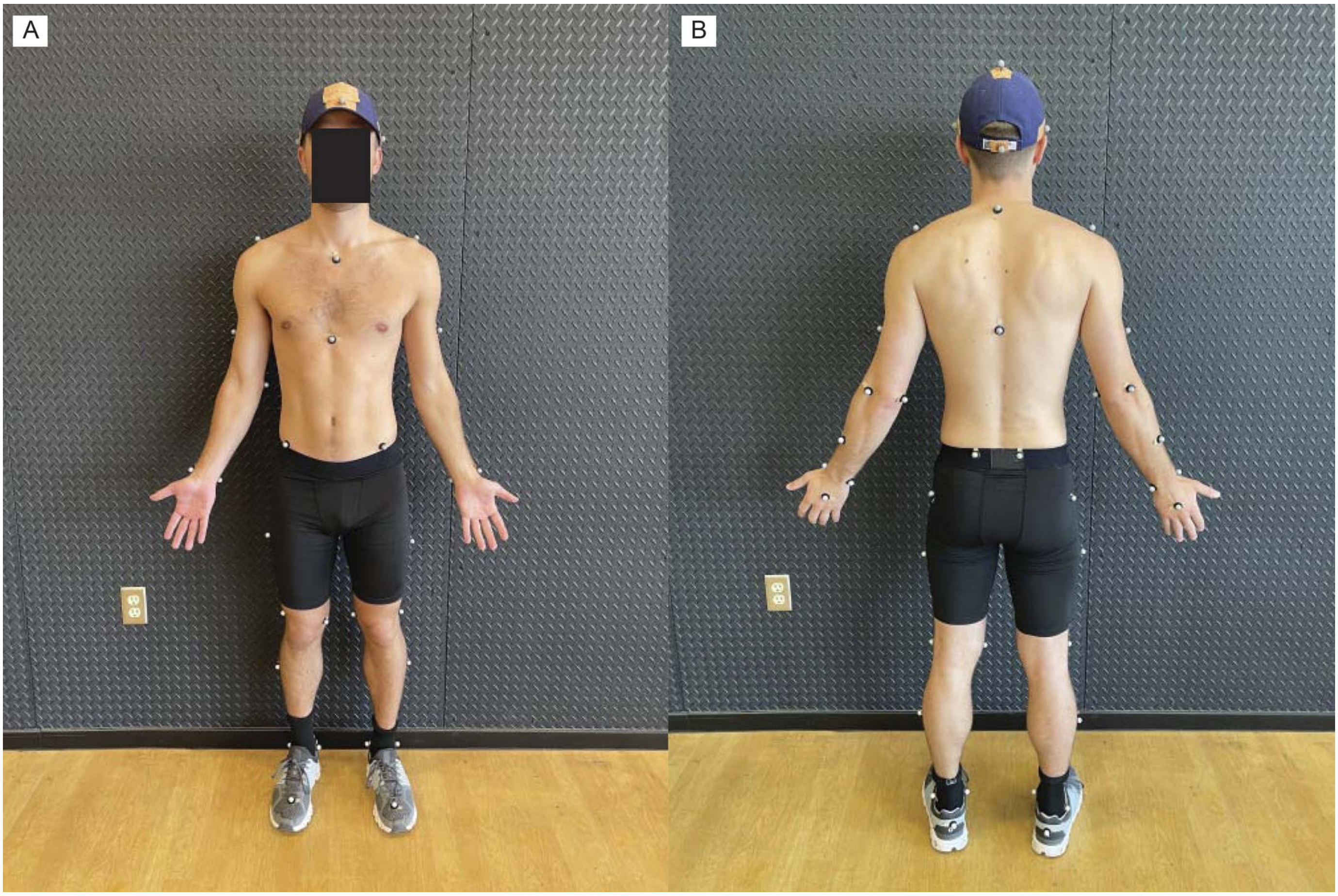

Figure 1. Marker placement. A, Anterior view. B, Posterior view. Reprinted with permission.[11]

tions between hip-strength measurements and biomechanical metrics. Correlations were assessed as *weak* ($0.1 < r < 0.3$), *moderate* ($0.3 < r < 0.5$), or *strong* ($r > 0.5$).[23] The α level was set at .01. We used SPSS (version 26; IBM Corp) to analyze the data.

RESULTS

The 26 high school pitchers in the study had an average fastball velocity of 33.7 ± 2.3 m/s. The means and SDs of the kinematics and strength are presented in Tables 1 and 2, respectively. The normalized peak EVT was 4.1% ± 0.6% body mass × height, and the normalized peak shoulder internal-rotation torque was 3.9% ± 0.6% body mass × height. Ten correlations (8 kinematics, 2 kinetics) were identified with $P < .01$ and $r > 0.5$, demonstrating strong correlations with hip strength (Table 3). Back-hip extension strength was correlated with the hip-to-shoulder separation angle at MER ($R^2 = 0.290$, $P = .005$) and BR ($R^2 = 0.316$, $P = .003$; Figure 3). When analyzing the kinetics, we identified that EVT was strongly correlated with both lead-hip abduction strength ($R^2 = 0.383$, $P = .001$) and back-hip abduction strength ($R^2 = 0.319$, $P = .003$; Figure

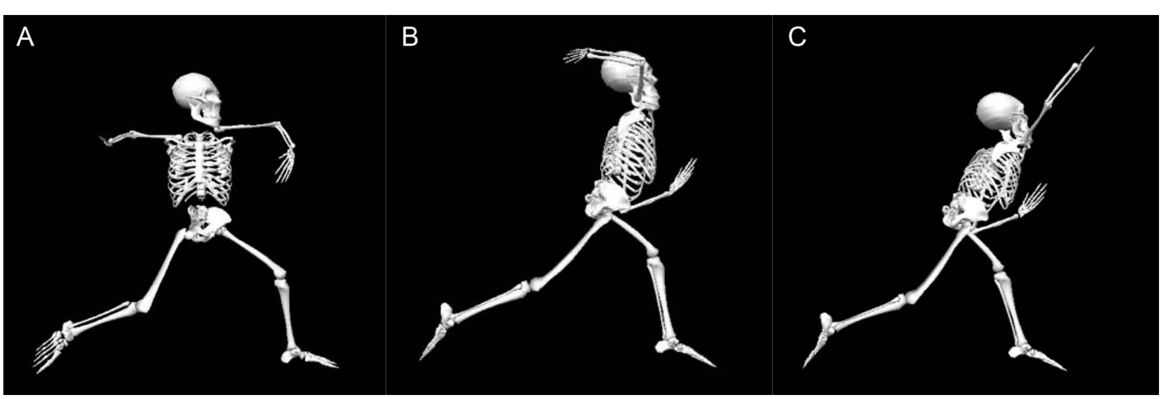

Figure 2. Renderings from Visual 3D (C-Motion, Inc) software displaying the 3 key moments in the pitching cycle. A, Foot contact. B, Maximal external rotation. C, Ball release.

Table 1. **Kinematics of Adolescent Baseball Pitchers at Foot Contact, Maximal Shoulder External Rotation, and Ball Release (Mean ± SD)**

Kinematics, °[a]	Foot Contact	Maximal External Rotation	Ball Release
Shoulder			
External rotation	23.5 ± 27.1	164.3 ± 14.4	106.0 ± 8.8
Abduction	83.7 ± 13.8	81.2 ± 6.9	87.6 ± 5.1
Horizontal abduction	−37.6 ± 11.8	−5.6 ± 10.6	−10.9 ± 11.5
Elbow flexion	98.9 ± 13.2	87.6 ± 10.6	33.7 ± 8.1
Pelvic rotation	−66.2 ± 12.2	8.6 ± 10.1	12.6 ± 9.7
Torso rotation	−95.3 ± 11.8	5.5 ± 8.5	14.2 ± 8.7
Hip-to-shoulder separation angle	28.1 ± 5.9	4.2 ± 6.7	−0.4 ± 7.3
Lead hip			
External (−), internal (+) rotation	−3.3 ± 15.3	9.5 ± 14.8	10.0 ± 15.7
Flexion	54.9 ± 12.6	83.3 ± 9.5	79.9 ± 11.3
Abduction (−), adduction (+)	−36.1 ± 8.6	10.2 ± 8.6	12.1 ± 7.9
Back hip			
External (−), internal (+) rotation	10.8 ± 11.7	−7.6 ± 10.0	−9.7 ± 12.3
Extension (−), flexion (+)	6.0 ± 13.6	−7.7 ± 5.9	−0.2 ± 7.3
Abduction (−), adduction (+)	−31.0 ± 7.2	1.7 ± 6.1	0.2 ± 6.3

[a] A negative metric indicates the segment (pelvis or torso) was rotated in a clockwise direction for the right-handed pitcher. A positive metric indicates the segment was in a closed position. For a right-handed pitcher, the lead foot was pointing toward the right-handed batter.

3). We observed no correlations between shoulder internal-rotation torque and hip strength. Full correlation results are provided in Supplemental Tables 1–4 (available online at http://dx.doi.org/10.4085/1062-6050-2020-20.S1). We noted 6 other correlations between pitching kinematics and hip rotational strength (Figure 4).

DISCUSSION

Our hypotheses were partially true. Back-hip extension strength was correlated with hip-to-shoulder separation angle at both MER and BR, whereas lead-hip extension strength was not correlated with pitching biomechanics. The EVT was correlated with both lead-hip and back-hip abduction strength, whereas no correlations were evident between shoulder internal-rotation torque and hip strength.

The *hip-to-shoulder separation angle*, which measures the angle formed between the pelvis and the upper torso, is a commonly evaluated kinematic variable in studies involving the pitching motion. We found strong correlations between this angle and back-hip extension strength at both MER ($r = 0.538$, $P = .005$) and BR ($r = 0.562$, $P = .003$). Back-hip extension is important for creating a longer stride length,[24] which has been correlated with velocity and proper set up of the lead-leg hip flexion because it allows pitchers to properly translate their pelvic rotational torque to the upper extremities.[3] Strong back-hip extensors allow pitchers to propel themselves forward to create more forward velocity during the pitching cycle.[25] The primary hip extensor is the gluteus maximus; Campbell et al[25] demonstrated this as active during the arm-cocking phase. This extension may allow pitchers to properly rotate at the pelvis, helping to transfer the lower extremity energy into the torso and throwing arm. The increased hip-to-shoulder separation angle created by this rotation has been associated with an increase in pitch velocity as well as a decrease in humeral rotation torque and elbow-valgus load.[9,26]

When evaluating peak kinetics, we observed that both lead-hip abduction strength ($r = 0.619$, $P = .001$) and back-hip abduction strength ($r = 0.565$, $P = .003$) were strongly correlated with normalized EVT. Back-hip abduction strength has been linked to greater pelvic rotation and the transfer of forces to the lead leg.[22] If the core muscles cannot appropriately control these increased forces, then the transfer of force has been shown to increase EVT at the

Table 2. **Hip-Strength Measures in Adolescent Baseball Pitchers (Mean ± SD)**

Variable, kg	Lead Hip	Back Hip
External rotation	11.2 ± 2.8	11.1 ± 2.8
Internal rotation	11.6 ± 2.5	11.1 ± 2.4
Flexion	20.4 ± 6.6	20.7 ± 6.0
Extension	15.8 ± 4.5	16.9 ± 4.0
Abduction	14.2 ± 3.3	15.0 ± 3.3
Adduction	11.9 ± 2.8	11.7 ± 2.7

Table 3. **Correlations Between Pitching Biomechanics and Hip Strength**

Variable	*r* Value	*P* Value[a]
Kinematics at maximal shoulder external rotation		
Shoulder horizontal-abduction angle and lead-hip internal-rotation strength	−0.564	.003
Shoulder horizontal-abduction angle and back-hip internal-rotation strength	−0.528	.006
Shoulder horizontal-abduction angle and back-hip external-rotation strength	−0.501	.009
Hip-to-shoulder separation angle and back-hip extension strength	0.538	.005
Kinematics at ball release		
Shoulder horizontal-abduction angle and lead-hip internal-rotation strength	−0.554	.003
Shoulder horizontal-abduction angle and back-hip internal-rotation strength	−0.520	.006
Hip-to-shoulder separation angle and back-hip extension strength	0.562	.003
Back-hip adduction angle and lead-hip internal-rotation strength	0.512	.008
Kinetics		
Normalized elbow-varus torque and lead-hip abduction strength	0.619	.001
Normalized elbow-varus torque and back-hip abduction strength	0.565	.003

[a] All *P* values in table indicate correlation ($P < .01$).

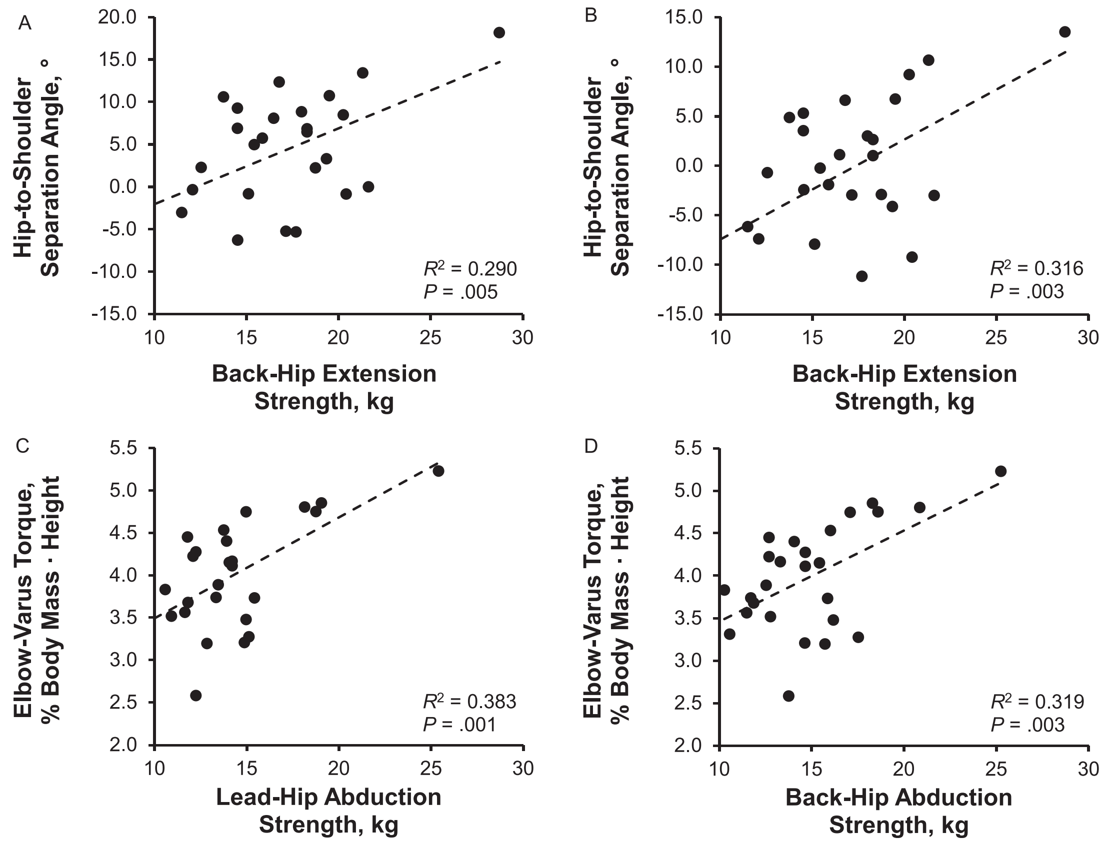

Figure 3. Scatterplots of the hypothesized correlations. A, Hip-to-shoulder separation angle at maximal external rotation and back-hip extension strength. B, Hip-to-shoulder separation angle at ball release and back-hip extension strength. C, Normalized elbow-varus torque and lead-hip abduction strength. D, Normalized elbow-varus torque and back-hip abduction strength.

elbow.[22] Earlier investigators[27] noted lead-leg hip-adduction torque was linked with higher-velocity pitchers. It is possible the lead-hip adduction was overpowered by the pitchers' lead-hip abduction, resulting in decreased pelvic rotation and increased EVT. Therefore, it may be important for athletes to ensure balance between their hip-abductor and hip-adductor strengths to avoid increased EVT, which has been associated with elbow injuries among professional baseball pitchers.[28]

Six other correlations were identified between pitching kinematics and hip rotational strength (Figure 4). During the pitching motion, the movement of the humeral head places the soft tissues of the shoulder joint under substantial stresses. Specifically, Takagi et al[29] found excessive shoulder horizontal abduction at MER increased anterior shear forces in the shoulder, elevating athletes' risk for injury. We determined that shoulder horizontal-abduction angle and lead-hip internal-rotation strength had strong negative correlations at both MER ($r = -0.564$, $P = .003$) and BR ($r = -0.554$, $P = .003$). According to electromyography studies published by Oliver and Keely,[30] at MER, the gluteus medius (a prominent muscle for internal rotation at the hip) is activated up to 145% of the maximal voluntary contraction and this is strongly correlated with pelvic rotation velocity. In addition, our data showed a strong positive correlation between lead-hip internal-rotation strength and back-hip adduction angle at BR ($r = 0.512$, $P = .008$). During the throwing motion, the lead-hip internal rotators help anchor the lead hip and leg, encouraging rotation while decelerating the hip after BR.[27] In support of these data, Kageyama et al[27] also showed that during the arm-cocking phase, the front hip was required to perform hip adduction and internal rotation to assist the pelvis in rotation. If pitchers lack the ability to rotate the pelvis, torsional energy via the upper trunk and shoulder may increase, resulting in increased shoulder horizontal abduction.[27] This suggests the importance of avoiding a deficiency in lead-hip internal-rotation strength because it may increase the chance of shoulder injury due to the anterior shear forces from greater shoulder horizontal abduction.

Along with the lead hip, the shoulder horizontal-abduction angle displayed correlations with the back hip. Back-hip external-rotation strength had a strong negative correlation at MER ($r = -0.501$, $P = .009$), and back-hip internal-rotation strength had strong negative correlations at both MER ($r = -0.528$, $P = .006$) and BR ($r = -0.520$, $P = .006$). Oliver and Keely[30] noted a pitcher's gluteus maximus (a prominent muscle for external rotation at the hip) of the back leg was highly activated during the arm-cocking and acceleration phases and identified a correlation between gluteus maximus external rotation and pelvic rotation. Calabrese[31] found a relationship between internal hip-rotator strength and pelvic rotation, again supporting the importance of good pelvic rotation to avoid overcompensating and thereby placing excessive torsion on the upper extremity. Ultimately, our data support previous research and indicate that stronger lead-hip and back-hip rotators may allow the body to better position the shoulder in horizontal abduction, helping to avoid dangerous force

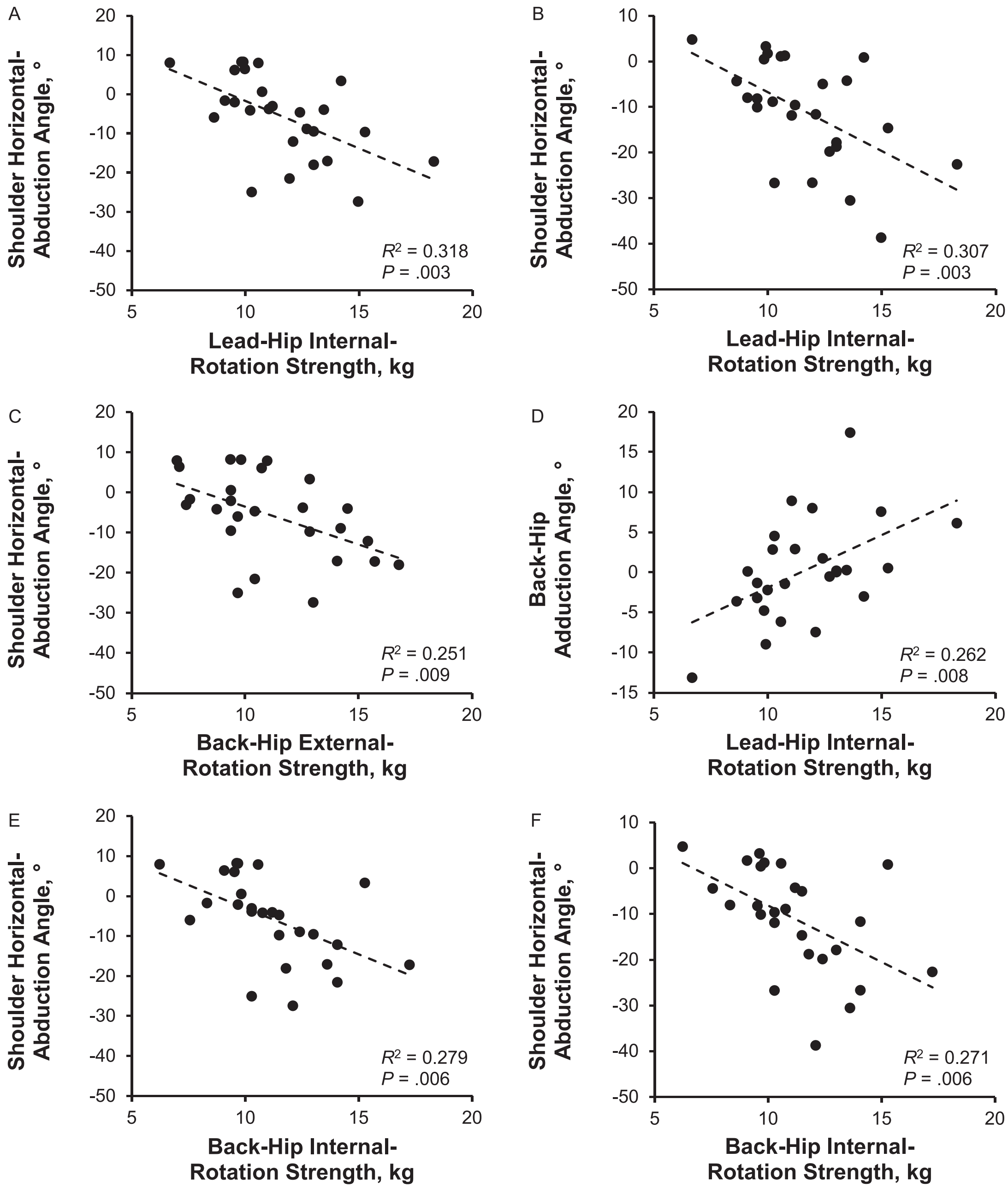

Figure 4. Scatterplots of the other correlations. A, Shoulder horizontal-abduction angle at maximal external rotation and lead-hip internal-rotation strength. B, Shoulder horizontal-abduction angle at ball release and lead-hip internal-rotation strength. C, Shoulder horizontal-abduction angle at maximal external rotation and back-hip external-rotation strength. D, Back-hip adduction angle at ball release and lead-hip internal-rotation strength. E, Shoulder horizontal-abduction angle at maximal external rotation and back-hip internal-rotation strength. F, Shoulder horizontal-abduction angle at ball release and back-hip internal-rotation strength.

thresholds. Exercises to strengthen both the internal and external hip rotators should not be overlooked by athletic trainers when working with pitchers because they may be beneficial in decreasing the risk for shoulder injuries.

Our study had limitations. First, a laboratory study can only show correlations at a single point. Whereas our data showed that both lead-hip and back-hip abduction strength were associated with higher EVT, we cannot necessarily say that increasing hip-abduction strength in an individual will lead to increased elbow torque. Future authors may include a multiple regression model that predicts biomechanical variables on the basis of hip-strength metrics. Second, no formal α correction was done as the large number of correlations would have made the α level very small, possibly leading to type II errors. To reduce type I errors, we set the α level at .01. Third, we only analyzed adolescent male pitchers, and the results may not be applicable to higher-level athletes because sequential timing differences may be present between professional and collegiate pitchers due to musculoskeletal development. Last, our results may have been influenced by segments of the kinematic chain not examined during this study, which may alter the observed isolated findings on the hips.

Our primary purpose was to clinically measure hip strength and investigate associations with pitching kinematics. Our specific hypotheses were partially true. In summary, back-hip extension strength was correlated with the hip-to-shoulder separation angle at both MER and BR, whereas lead-hip extension strength was not correlated with pitching biomechanics. The EVT was correlated with both lead-hip and back-hip abduction strength, whereas no correlations were seen between shoulder internal-rotation torque and hip strength. Previous researchers demonstrated the importance of the segmental kinematic chain during the pitching cycle; however, focused studies on the relationship with hip strength are lacking. We identified key correlations involving hip-rotation strength, which can aid future pitchers by highlighting muscle groups to exercise appropriately in order to improve performance and decrease the injury risk.

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