Passive Ranges of Motion of the Hips and Their Relationship With Pitching Biomechanics and Ball Velocity in Professional Baseball Pitchers

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Passive Ranges of Motion of the Hips and Their Relationship With Pitching Biomechanics and Ball Velocity in Professional Baseball Pitchers

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Investigation performed at the American Sports Medicine Institute, Birmingham, Alabama

Background: Pelvis and trunk motions during baseball pitching are associated with ball velocity. Thus, limits in hip flexibility may adversely affect pitching biomechanics and the ability to generate ball velocity.

Hypotheses: Professional baseball pitchers will have less passive range of motion in the nondominant hip and the measured ranges of motion of both the nondominant and dominant hips will correlate with biomechanical parameters of the lower extremity among professional pitchers.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Nineteen healthy professional baseball pitchers volunteered for testing. Fluid goniometry was used to measure passive range of motion of adduction (ADD), abduction (ABD), internal rotation, external rotation, total arc of rotation, and total arc of ADD + ABD. Pitching biomechanical data were collected using an automated 3-dimensional motion analysis system while participants threw fastballs.

Results: Pitchers possessed significantly less passive range of motion in the nondominant hip when compared with the dominant hip for all ranges. Total arc of rotation of the nondominant hip correlated with ball velocity ($r = .50$). Total arc of ADD + ABD in the nondominant hip and ABD in the nondominant hip were correlated with stride length ($r = -.72$ and .70, respectively). Dominant hip ABD ($r = .63$), total arc of rotation in the nondominant hip ($r = -.45$), and total arc of ADD + ABD of the dominant hip ($r = .44$) were correlated with trunk separation. Total arc of ADD + ABD of the nondominant hip ($r = -.52$) and total arc of rotation of the dominant hip ($r = -.44$) were correlated with pelvic orientation.

Conclusion: Passive range of motion is smaller in the nondominant hip than the dominant hip among professional pitchers. The measured disparity between the hips is significantly correlated with various pitching biomechanical parameters of the trunk and pelvis. Future research is required to investigate a causal relationship between less hip passive range of motion and both ball velocity and pitching biomechanics.

Keywords: external rotation; internal rotation; abduction; adduction; biomechanics; baseball; hip

Hip disorders among elite athletes are prevalent. Athletes in power sports have particularly high risks for hip osteoarthritis later in life (odds ratio of 2.2), but throwers also exhibit increased risk.[22] L'Hermette et al[26] suggest that 60% of former professional handball players developed osteoarthritis in the hips. Quantifying hip range of motion (ROM) and its relationship with pitching can facilitate injury risk management and optimal performance.

Overhand throwing, or pitching, involves an interaction and sequencing of the lower extremity to generate and transmit energy to the trunk and upper extremity to produce maximal ball velocity.[11,34] The hip has been demonstrated to be the primary joint initiating spinal rotation during trunk rotation.[24] During the pitching motion, pelvic orientation and angular velocity influence torso (spine) rotation.[35] During the stride and arm acceleration phases of the pitching motion, a rapid sequence of pelvic rotation followed by trunk rotation produces maximum upper torso angular velocity and maximum glenohumeral external rotation.[7,8,35,36]

A commonly observed adaptation among pitchers has been glenohumeral internal rotation deficits (GIRD) with

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repetitive throwing. Such an adaptation involves capsular contraction, humeral head retroversion, muscular tightness, rotator cuff weakness, capsular laxity, and osseous adaptations.[4,6,30,37] Adaptive changes during athletic activities that affect the hips include limitations in hip ROM commonly associated with hip abductor muscle weakness in various sports,[19,20,33] including baseball,[23] all with altered motor control.[21] Such adaptations can produce cumulative microtrauma, which may lead to joint contractures,[1,31] structural changes,[20,21] and altered kinematics of both the hip joint and pelvis.[2,38] A force equal to approximately 1.75 times body weight is produced in the nondominant or lead leg, as it supports the pitcher and transfers energy to the trunk through this hip.[27] Consequently, improper loading technique and inadequate muscular adaptations during the pitching motion may lead to hip maladaptations, resulting in a hindrance to pitching performance or ball velocity.[3,13,14,32]

Few studies have investigated hip ROM and performance in overhead athletes. Ellenbecker et al[10] described a greater prevalence of limitation in active hip external rotation (42%) than hip internal rotation (17%) among professional baseball players, which was not statistically significant. This study did not correlate ROM with performance or biomechanical parameters. A recent investigation by Laudner et al[23] confirmed that pitchers do have less internal rotation in the trail or dominant leg compared with positional baseball players, but no significant difference was observed within pitchers between hips. While evidence of hip rotational differences side to side among overhead athletes do exist, correlations between hip ROM, ball velocity, and pitching biomechanics have not been studied.

The purpose of this study was to describe side-to-side differences in passive ROM (PROM) of the hips among professional baseball pitchers. The secondary analysis was to determine correlations between their hip PROM and their pitching biomechanics and ball velocity.

METHODS

This study was approved by the Institutional Review Board. Nineteen male professional baseball pitchers were recruited with a height of 192 ± 0.06 cm and a mass of 96.3 ± 11.1 kg, as similarly observed in previous studies.[10,23] Ten right-handed pitchers and 9 left-handed pitchers participated in this study. All participants reported no recent (12-month) history of upper extremity, spine, or lower extremity injury at the time of study, and had not undergone surgery in the previous 12 months. All testing occurred in the biomechanics laboratory. Upon arrival at the biomechanics laboratory, each participant completed a written informed consent, medical history, and baseball background. All participants were playing professional baseball at the time of the study.

Passive Range of Motion

Measurements of bilateral hip PROM were conducted by 2 examiners. One positioned the extremity and the other aligned and read the goniometer. The examiner positioning the hip was blinded to the results of the measurement. The order of the measurements performed was randomized prior to data collection.

Hip PROM was measured using a fluid goniometer. Rotational measurements were collected with the participant in the prone position (Figure 1). A strap was placed over the posterior sacroiliac spine for stabilization and minimization of pelvic movement. The measured hip was placed in 0° of abduction with the contralateral hip in 30° of abduction. The ipsilateral knee to the hip being measured was flexed to 90° and the therapist passively moved the leg to produce hip rotation (external rotation and internal rotation). Movement was stopped and rotation was measured when a resistive end feel was achieved in the hip. The goniometer was aligned vertically along the diaphysis of the tibia. This position was chosen because of the increased stability of the lumbopelvis in a prone position[12] to provide a more accurate measure of hip PROM. Using this method, previous investigations produced very good intrarater/interrater examiner reliability of intraclass correlation coefficients of .97 and .98, respectively.[12] Total arc of rotation was computed as the sum of external rotation plus internal rotation.

Adduction (ADD) and abduction (ABD) measurements were performed with the participant in the supine position and the hip being measured in 15° of flexion (Figure 2). The flexion angle was measured with the same bubble goniometer. The goniometer was aligned along the femur and the plane of the table the patient was lying on and the axis of rotation of the goniometer was placed over the greater trochanter. Adduction of the hip was measured with the same knee position as with hip ABD. Hip ABD PROM was stopped when either anterior superior iliac spine (ASIS) became elevated. The ASIS on the ipsilateral side typically elevated first with this maneuver, so the measurement was taken at the onset of ipsilateral ASIS movement.[28] The total arc of ABD + ADD was computed as the sum of ABD plus ADD.

Thus 10 PROM parameters were measured for each participant. This included 4 measurements for each hip: external rotation, internal rotation, ABD, and ADD. Two additional parameters were computed, total arc of rotation (external rotation + internal rotation) and total arc of ABD +ADD, for a total of 12 PROM parameters. The right hip was considered the dominant hip for each right-handed pitcher; the left hip was considered the dominant hip for each left-handed pitcher.

Biomechanical Testing

Each participant's pitching biomechanics were measured with a protocol previously described.[8,14,15,17,18,29] Participants wore spandex shorts and no shirt to limit movement of the markers from the anatomical landmarks during

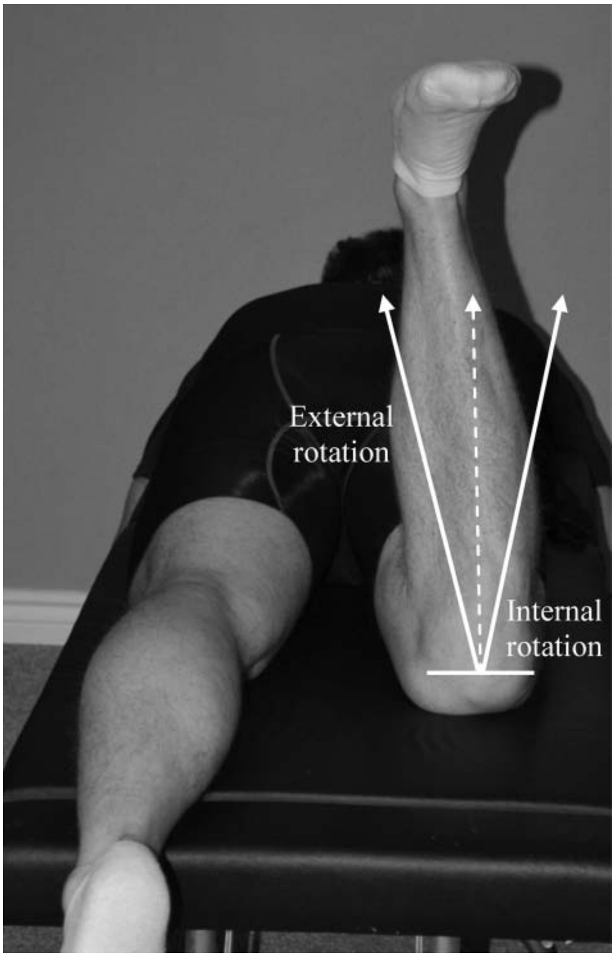

Figure 1. Internal and external rotation of the hip joint.

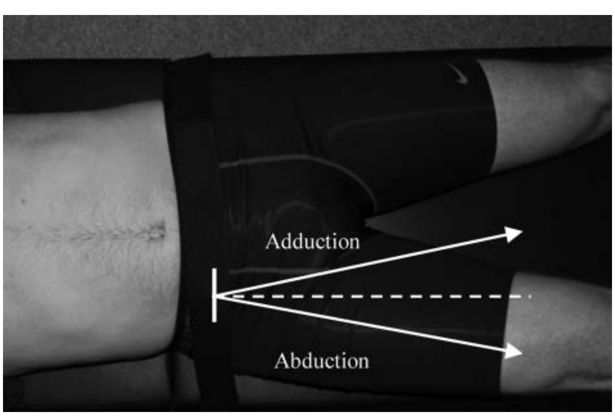

Figure 2. Adduction and abduction of the hip joint.

pitching motion. Reflective markers (1.27 cm in diameter) were attached bilaterally to the proximal aspect of the second metatarsal, lateral malleolus, lateral femoral epicondyle, greater femoral trochanter, superolateral process of the acromion, lateral humeral epicondyle, and ulnar styloid. Two additional markers were attached on the throwing hand, at the radial styloid and proximal end of the third metacarpal.

The participant was given unlimited time to stretch and warm up before data collection began. The participant pitched from a portable mound (Athletic Training Equipment Co, Sparks, Nevada) toward a strike zone ribbon located over a home plate, 60.6 ft (18.4 m) away. Each participant threw 10 fastballs from the wind-up in an overhead position. Ball velocity was captured using a Tribar Sport radar gun (Jugs Pitching Machine Co, Tualatin, Oregon) from behind home plate. The radar gun was accurate to ±0.2 m/s (0.5 mph).

An automated digitizing motion analysis system (Eagle System, Motion Analysis Corporation, Santa Rosa, California) was used to measure the individual's motion during the fastest 3 pitches (averaged) that entered the strike zone. Eight synchronized 240-Hz digital cameras captured the location of the reflective markers on the participant during each pitch. Three-dimensional motion was calculated using the direct linear transformation method described by Wood and Marshall.[39] The positioning of the markers was filtered with a 13.4-Hz low-pass filter.

Seven biomechanical parameters were calculated for each pitcher (Figure 3). Six of these were position parameters measured at the instant of lead-foot contact: stride length, lead-foot position, lead-foot angle, pelvic orientation angle, upper trunk angle, and lead-knee flexion. Stride length was computed as the distance from the lead foot at contact to the rubber on the mound, expressed as a percentage of the participant's height. The pelvic vector was derived as the line through adjacent points located on the posterior sacroiliac crests in the frontal plane. The vector for the torso was attained through the acromioclavicular joints in the frontal plane. Three parameters were measured during the arm cocking phase: maximum pelvic angular velocity, maximum upper torso angular velocity, and maximum trunk separation velocity. Angular velocities of the pelvis and upper torso were calculated using a method described by Feltner and Dapena.[14] Trunk separation velocity was calculated as the rate of change between the pelvic and torso vectors. Lead-knee flexion was quantified a second time, at the instant of ball release.

Statistical Analysis

Side-to-side differences were compared for 6 hip PROM parameters (external rotation, internal rotation, total excursion rotation, ABD, ADD, and total excursion ABD + ADD). A 2-tailed t test was considered significant if the P value was <.05. Before data collection, a power analysis with a β of .2 and an α of .05 was used to determine that a sample size of 19 was required to detect side-to-side differences[5] in hip PROM of greater than 10°.[10] The Pearson rank correlation coefficient was used to evaluate the correlations between hip PROM before pitching with ball velocity and with each of the 10 biomechanical parameters. All statistical analyses were performed using SPSS 10.0 (SPSS, Inc, Chicago, Illinois).

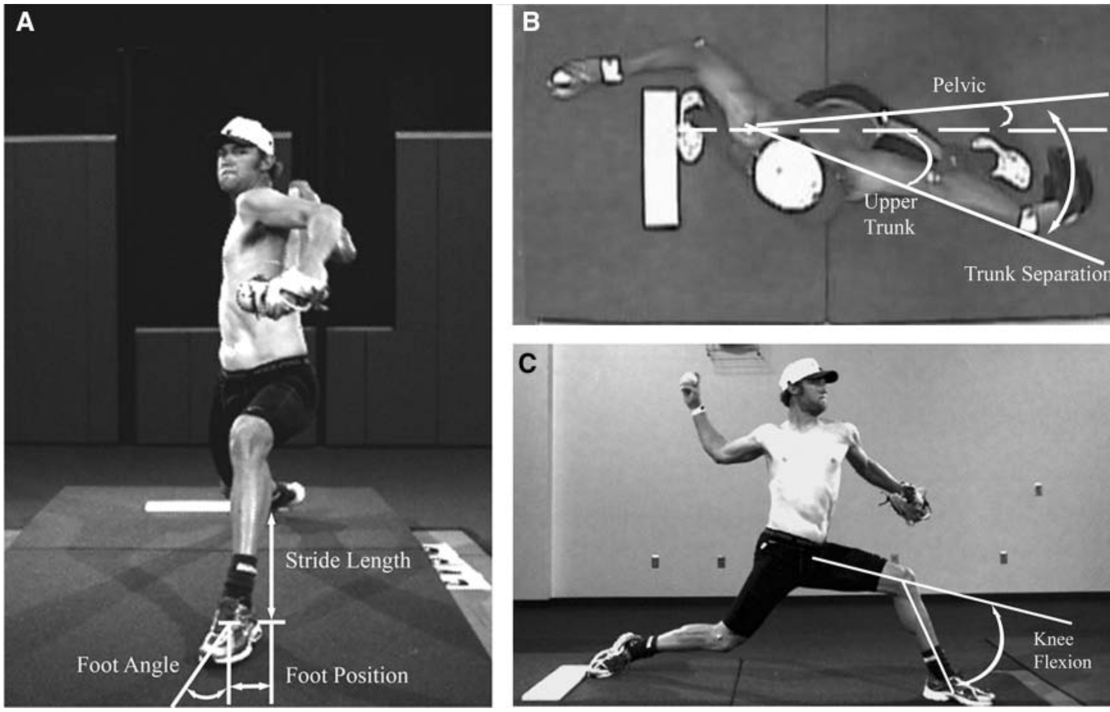

Figure 3. A, at early cocking phase, the biomechanical parameters measured include foot angle, foot position, and stride length. B, at early cocking phase, trunk separation is derived from the pelvic and upper trunk angles. C, at early cocking phase, knee flexion is measured using the thigh and lower leg.

TABLE 1
Paired *t* Test Analysis of Hip Range of Motion (deg) Among Professional Pitchers[a]

Range of Motion	Dominant	Nondominant	Level of Significance
External rotation	44.0 ± 9.0	35.6 ± 5.8	$P < .001$
Internal rotation	50.8 ± 9.2	31.3 ± 6.2	$P < .001$
Total arc of rotation	94.8 ± 13.3	67.0 ± 7.7	$P < .001$
ADD	50.8 ± 8.4	31.6 ± 6.2	$P < .001$
ABD	43.4 ± 12.0	35.7 ± 10.7	$P = .06$
Total arc of ADD + ABD	94.2 ± 13.9	67.3 ± 12.3	$P < .001$

[a]ADD, adduction; ABD, abduction.

RESULTS

The mean (± standard deviation) ball velocity was 38.8 ± 1.3 m/s, with a range of 36.3 to 41.1 m/s. Side-to-side hip PROM data are shown in Table 1. The nondominant hip had less PROM than the dominant hip in all directions measured. All differences were statistically significant, except for ABD ($P = .06$).

Significant correlations are shown in Table 2. One hip PROM parameter (total arc of rotation) was significantly correlated with ball velocity. The biomechanical parameters found to have significant correlations with hip PROM were trunk separation velocity, pelvic orientation, and stride length. Both ABD and total arc of ADD + ABD of the nondominant hip correlated with stride length. Three hip PROM parameters (ABD of the dominant hip, total arc of ADD + ABD of the dominant hip, and total arc of rotation) correlated with trunk separation velocity. Total arc of ADD + ABD of the nondominant hip and total arc of rotation of the dominant hip both correlated with pelvic orientation.

DISCUSSION

This study demonstrated that PROM was significantly less on the nondominant hip compared with the dominant hip. This difference would suggest a femoroacetabular rotational deficit, a form of labeling similar to the clinical findings documented with the GIRD of the thrower's shoulder. Ellenbecker et al[10] were the first to measure active hip ROM among professional pitchers and found no statistically significant side-to-side differences, although they did report that 17% and 42% of pitchers had an observable difference of ≥10° in active internal rotation and external rotation, respectively. The lack of statistical agreement with the current study may be attributable to differences in measurement methodology. The current study used fluid goniometry to measure PROM, while Ellenbecker et al[10] measured angles by digitizing points in 2-dimensional images (ie, measuring angles from 1 still-camera view). Both angle measurement systems have inherent limitations in accuracy. The second difference was that Ellenbecker

TABLE 2
Significant Correlations with Hip Range of Motion[a]

Passive Hip Range of Motion	Correlated Parameter	Correlation, *r*	Significance, *P*
Correlations with ball velocity			
Total arc of rotation of the nondominant hip	Ball velocity	.50	.04
Correlations with biomechanics			
Total arc of ADD + ABD, nondominant hip	Stride length	–.72	.002
ABD, nondominant hip	Stride length	.70	.003
Abduction, dominant hip	Trunk separation velocity	.63	.004
Total arc of ADD + ABD, nondominant hip	Pelvic orientation	–.52	.04
Total arc of rotation, nondominant hip	Trunk separation velocity	–.45	.05
Total arc of ADD + ABD, dominant hip	Trunk separation velocity	.44	.05
Total arc of rotation, dominant hip	Pelvic orientation	–.44	.05

[a]ADD, adduction; ABD, abduction.

et al[10] used active ROM while the current study used PROM. Passive ROM permits assessment of the entire physiologic range of the hip, which can detect aberrant arthrokinematics (loss of accessory motion) and identify acquired adaptations of soft tissue or capsular tightness. This acquired adaptation of tissue tightness in the hip would be analogous to the acquired tightness observed among pitchers with posterior glenohumeral tightness (ie, GIRD). Measurement of active ROM assesses the functional range, but does not assess the remaining physiologic range available. A lower measurement value in PROM of the nondominant hip may be attributed to repetitive exposure to large landing forces, as previously studied.[27]

More recently, work by Laudner et al[23] compared hip PROM between professional baseball pitchers and position players using a digital inclinometer. These authors concluded that there was a significant difference in PROM for internal rotation within pitchers. Furthermore, this study concluded that professional pitchers had significantly less internal rotation when compared with position players. The methods from our study contrast with those of Laudner et al[23] in several ways. First, different measurement tools (digital inclinometer vs fluid goniometer) were used to obtain quantitative values of PROM. Use of different instruments does not permit the direct comparison of measurements. Even though both studies measured PROM, Laudner et al[23] had their participants sitting during measurements, which can reduce available range because of compressive forces of the joint and the inconsistent position of the trunk-pelvis altering the axis of rotation at the acetabulum.[12]

In the current study, side-to-side differences in measured PROM of the hips correlated with trunk and pelvis biomechanics during pitching. Although individual hip range did not correlate with ball velocity, less total arc of rotation in the nondominant hip was significantly correlated with ball velocity. The hip PROM measurements were performed only once; therefore, conclusive support of the effect on ball velocity is unknown at this time. Further investigation over time is needed in order to determine the effect on ball velocity.

During the pitching motion, the nondominant hip externally rotates to achieve proper foot contact and align the pelvis to generate kinetic force from the leg drive. Internal rotation occurs during the arm-cocking and arm-acceleration phases of the pitching motion. The smaller ranges of PROM in the nondominant hip measured in this study may result in compensatory and excessive motion in the spine and shoulder to accommodate the motion and maintain arm and ball velocity. Wright et al[40] confirmed that hip rotation is correlated with foot-contact position and pelvic alignment. If an excessive amount of rotation occurs at the hips, then the pelvis and foot are in a more open position, thereby prematurely initiating the arm-cocking phase and resulting in the loss of kinetic energy from the lower extremity. This would result in greater torque being generated at the shoulder with less energy from the lower extremity; the shoulder must generate greater torque than usual to produce the desired ball velocity. Conversely, if hip rotation is smaller, closed positions at the foot and pelvis occur and the pitcher is forced to pitch across the body, which would limit the kinetic energy transfer from the lower extremity into the arm. It should be noted that previous research has indicated that there are both upper and lower limits to each biomechanical angle measurement that correlate to optimum performance and safety.[8,9,16,18] Because excessively high and low angles during pitching may be detrimental, both positive and negative correlations between PROM and angles may be undesirable. However interpretation of correlations with angular velocity is clearer; decreased angular velocity should be avoided. Thus any PROM with a negative correlation to angular velocity is undesirable.

During the arm-cocking phase, total arc of motion ABD + ADD of the dominant hip was positively correlated with trunk separation velocity. This relationship would suggest that larger ranges in the dominant hip facilitate greater angular velocity of the pelvis as this is the leg that initiates the forward momentum of the pitching motion. Presumably, having more range would permit greater kinetic energy production, ultimately producing greater ball and angular velocity. Of the total arc of motion (ABD + ADD), only ABD in the dominant hip was found to have a positive correlation with trunk separation velocity. In this study, trunk separation was 964 deg/s compared with previous work[8] that estimated values of 1100 deg/s. Our values are lower, which could be attributed to the negative contributions from other ranges of motion.

Bilateral total arc of motion ABD + ADD was demonstrated to correlate with stride length, pelvic orientation, and trunk separation velocity. The total arc of motion ABD + ADD of the nondominant hip was observed to be negatively correlated with stride length and pelvic orientation at foot contact. The correlation would suggest that this relationship is undesirable for a professional pitcher as it would seem to minimize the stride length and compromise the transfer of kinetic energy from the lower extremity and into the throwing arm. Bilateral total arc of rotation was also found to be associated with pelvic and trunk biomechanics. The dominant hip was negatively correlated with pelvic orientation. This would suggest that with more overall rotational PROM, a greater opened orientation of the pelvis at foot contact would occur. The open pelvis would result in premature transfer of kinetic energy from the legs with loss of momentum into the upper extremity. However, the degree of orientation by the participants in this study was more than adequate, which could be a result of the balance by the negative impact of the total arc of rotation that would result in a more closed pelvic orientation. A discussion on this interesting relationship between PROM and pelvic orientation during pitching requires further investigation.

Total arc of rotation of the nondominant hip was negatively correlated with trunk separation velocity. This association would suggest that with less rotational PROM, trunk angular velocity would be limited, which is undesirable. However, the abduction of the dominant hip was found to have a greater correlation than the nondominant hip (.63 vs –.44). This might suggest a compensatory mechanism because of the loss in PROM in the nondominant hip, or it may be merely an acquired adaptation of an elite pitcher. Future research is necessary to determine the critical ranges of the hips necessary to optimize trunk separation velocity.

Thus, based on the results of this study, there are several potentially clinically relevant concepts to consider and to investigate in the future. Pitchers require adequate hip rotation, ABD flexibility, and PROM to ensure proper pitching mechanics. Hip ABD strength appears important in maintaining hip ABD PROM, as suggested by previous authors who correlated a lack of PROM to weakness in the hip musculature.[19,20,25,33] The threshold, or range, in hip ROM that would be optimal is unknown, and requires further research in order to determine the effect on both biomechanical parameters and ball velocity in baseball pitchers.

The current study has several limitations. First, a detailed history of previous lower extremity injuries was not obtained. Obtaining a detailed history of lower extremity injuries is recommended in future studies to account for confounders associated with loss in hip range. Second, flexion and extension were not recorded. Future inclusion of flexion and extension ranges of motion is necessary to complete the understanding of the hips' role in lower extremity biomechanics. Lastly, these results reflect professional pitchers and not lower-level baseball pitchers.

CONCLUSION

Healthy professional pitchers possess less PROM in the nondominant hip compared with the dominant hip. This difference would suggest a femoroacetabular rotational deficit. This study demonstrated that less PROM in the nondominant hip correlated with ball velocity and biomechanical parameters among professional pitchers. Thus, physical therapy and conditioning to regain hip PROM may help the professional pitcher optimize mechanics and ball velocity. Further research is warranted to ascertain if increasing the ROM in the nondominant hip will increase ball velocity. Further study investigating the effects the volume of pitching and the length of the playing season have on the acquisition of femoroacetabular deficits and resultant hip injury is suggested, to establish a causal relationship.

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