Influence of Pelvic Rotation on Lower Extremity Kinematics, Elbow Varus Torque, and Ball Velocity in Professional Baseball Pitchers

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Background: Early pelvic rotation has been associated with decreased throwing arm kinetics in college baseball pitchers, though professional pitchers have yet to be examined.

Purpose: To investigate the effect of pelvic rotation on trunk, pelvis and lower extremity kinematics, as well as throwing arm kinetics and pitch velocity in professional baseball pitchers.

Study Design: Descriptive laboratory study.

Methods: Data were analyzed for 157 professional baseball pitchers throwing fastballs using 3-dimensional motion capture (480 Hz). Pitchers were divided into an open pelvis (rotated toward target; n = 78) and a closed pelvis (n = 79) group based on pelvic rotation at foot contact. Variables of interest were compared between the groups using t tests and 2-way analysis of variance, while Spearman correlation was used to measure relationships between the variables of interest.

Results: Pitchers in the open group had a longer stride length (81% ± 5% vs 77% ± 5% body height; P < .01, d = 0.74), greater lead knee flexion (49° ± 6° vs 47° ± 10°; P = .043, d = 0.33), faster peak knee extension velocity (424°/s ± 158°/s vs 325°/s ± 142°/s; P < .01, d = 0.66), and faster ball velocity (39.1 ± 1.7 m/s vs 38.4 ± 2.1 m/s; P = .029, d = 0.35) compared with those in the closed group. There was no significant difference in elbow varus torque between the 2 groups (open: 87.8 ± 17.9 N m, closed: 90.5 ± 17.2 N m; P = .311). There were moderate negative relationships between pelvic rotation at foot contact and stride length (rS = -0.385, P < .001), lead knee extension (rS = -0.429, P < .001), and peak lead knee extension velocity (rS = -0.359, P < .001).

Conclusion: Professional pitchers who landed with an open pelvis demonstrated longer stride length, greater lead knee extension, faster lead knee velocity, and faster ball velocity compared with pitchers with a closed pelvis at foot contact. This increase in segment velocities and ball velocity was not associated with an increase in elbow varus torque and displays a potentially efficient method in which pitchers can increase ball velocity without an increase in elbow varus torque.

Clinical Relevance: Instructing pitchers to rotate their pelvis toward the target at foot contact may allow pitchers to transfer momentum up the kinetic chain more efficiently, while producing greater ball velocity and limiting the torque sustained at the elbow.

Keywords: knee extension; pitching; rotational velocity

For baseball pitchers, pitch velocity and command are essential components for competitive success. The generation of optimal pitch velocity has been shown to rely on proper motion and coordination of the lower body, pelvis, trunk, and throwing arm.12,14,29 Limitations in the transfer of energy to each segment due to variations or decrements along the kinetic chain have been shown to affect pitch velocity, diminishing performance while increasing the risk of injury by placing increased stress on the shoulder and elbow.1,2,18 Altered pelvic or trunk movement and strength have been suggested to lead to a “break” in the proper sequencing of the kinetic chain, limiting appropriate energy transfer.4 To maximize the contribution of the trunk, pitchers need to be in a position to optimally rotate the pelvis during the arm cocking phase.34 Previous investigations have demonstrated greater pitch velocity in pitchers with higher maximum pelvic and trunk rotational velocities, as well as greater pelvic rotation at maximal external rotation and ball release.8,19,22,33,34
The lead leg has been suggested to dictate pelvic rotation, serving as an anchor in converting forward and vertical momentum into rotational movement. In addition, the effect of stride length has been shown to influence the timing of a pitch and may indirectly lead to increased elbow loading. Professional pitchers with a longer stride length have also been reported to possess greater pelvic rotation compared with pitchers with a short stride. Theoretically, the longer the stride length, the more time the pitcher has before the foot contacts the ground, enabling greater pelvic rotation during the pitch cycle. Moreover, large variations in pelvic rotation between pitchers have been observed at foot contact. The position of the pelvis at landing may contribute to inefficient energy transfer either by limiting the ability of the pelvis to rotate fully or by transferring energy to the trunk and throwing arm too early. Meister reported alterations in the kinematic chain in pitchers who "opened up too soon" (ie, increased pelvic rotation at foot contact). Pitchers landing with an "open" pelvis (rotated toward the batter) have been theorized to limit efficient energy transfer through the kinetic chain, decreasing ball velocity, and placing increased stress on the throwing arm when compared with pitchers landing with a "closed" pelvis (remaining rotated away from the batter).

The ability to efficiently transfer energy from the lead knee to the pelvis and trunk has been shown to increase ball velocity in high school, college, and professional pitchers. A recent investigation examining youth, high school, college, and professional pitchers reported that premature pelvic rotation at foot contact was theorized to be related to increased kinetics across the throwing arm; however, kinetics were not actually analyzed in the investigation. The only study to investigate pelvic rotation at foot contact reported that high school and college pitchers who landed early (with an open pelvis) experienced reduced throwing arm kinetics and the same ball velocity compared with pitchers who landed late (with a closed pelvis).

The purpose of this investigation was to analyze lead knee and pelvic kinematics, throwing arm kinetics, and ball velocity in professional pitchers based on pelvic position (open vs closed) at foot contact. We hypothesized that pitchers who land with an open pelvis would have longer stride length, decreased peak knee extension velocity, decreased peak pelvic rotation velocity, and decreased ball velocity compared with pitchers who land with a closed pelvis.

**METHODS**

This study included a retrospective review of 157 professional baseball pitchers. Inclusion criteria for study participation included professional pitchers who were actively on a roster spot on a Major League or Minor League (Low A, High A, AA, and AAA) team at the time of testing. In addition, all pitchers had to have no record of serious injury at the time of testing, defined as any injury requiring more than 2 weeks of rest or rehabilitation within 6 months of testing. All overhand pitch types were allowed, and there were no submarine pitchers. Pitchers had been previously tested at Motus Global. As all data were deidentified before distribution, this study was exempt from institutional review board review under federal guidelines. All pitchers completed a privacy waiver that provided consent for study inclusion.

Based on the median pelvic rotation at foot contact for the 157 pitchers (62°), the pitchers were split into 2 groups: an open group (n = 78; mean age, 22.1 ± 2.0 years; height, 187.9 ± 4.9 cm; weight, 91.8 ± 8.0 kg; 50 right-handed/27 left-handed) and a closed group (n = 79; mean age, 21.8 ± 1.7 years; height, 183.4 ± 5.8 cm; weight, 95.3 ± 9.2 kg; 60 right-handed/19 left-handed).

Pitching evaluations were conducted as described previously. Testing occurred either during spring training or fall instructional league when pitchers were prepared to throw competitively in a game. Demographic data recorded for each pitcher included age, preferred throwing arm, years of professional experience, and injury history. Pitchers’ height and weight were then measured. The pitcher was given unlimited time to warm up with his preferred routine to pitch at maximal effort. Once warmed-up, 46 reflective markers were placed on anatomic landmarks to create a full body model. Position coordinate data of the reflective markers were collected with a 3-dimensional motion capture system using an 8-camera system (Motion Analysis Corp) at 480 Hz. The global coordinate system was established based on International Society of Biomechanics...
lated as previously described.7,19 Elbow varus torque was calculated the knee was fully extended (Figure 1C). Knee velocity for each pitcher was used for the analysis to represent the “best” performance, as reported in previous investigations.19,25,26,35

After marker application, pitchers were allowed more time to pitch from a mound to feel ready to pitch at maximum effort. Pitchers were instructed to pitch 8 to 12 fastballs with game-like effort from a regulation dirt mound to a catcher behind home plate at regulation distance (18.4 m). Pitchers threw only fastballs and were instructed to aim down the middle of the strike zone. Ball velocity was collected with a radar gun positioned behind the pitcher (Stalker Sports Radar). The pitch with the fastest ball velocity for each pitcher was used for the analysis to represent the described changes in lead knee flexion across the 4 separate phases of the pitch, beginning at foot contact (when the pelvis was designated as open or closed). Partial $\eta^2$ was used for estimating effect size of the ANOVA interactions.

Separately, independent-samples t tests were used to compare pitching variables (pelvic rotation at foot contact, stride length, lead knee flexion at foot contact, and lead extension), as well as velocities (peak lead knee extension velocity, peak pelvic rotation velocity, ball velocity), and elbow varus torque (absolute and normalized) between groups. Each of these variables was categorized into its respective kinematic and kinetic principles, and a Bonferroni-corrected $P$ value was used to account for potential familywise error rates36: $P < .0125$ for pitching variables, $P < .016$ for velocities, and $P < .05$ for elbow varus torque.

The Spearman rank correlation coefficient ($r_S$) was used to analyze the relationships among ball velocity, pelvic rotation at foot contact, stride length, lead knee extension, peak lead knee extension velocity, peak pelvic rotation velocity, ball velocity, and elbow varus torque; $r_S$ values were interpreted as weak ($\leq 0.30$), moderate ($0.31-0.50$), or strong ($\geq 0.50$).5,16 Cohen $d$ values were calculated to assess effect size for each independent-samples t test. When necessary, values of 0.20, 0.50, and 0.80 were used to characterize small, medium, and large effect sizes, respectively.5 For all analyses, statistical significance was set at $P < .05$. All statistical analyses were performed in IBM SPSS (version 23; IBM Corp).

**RESULTS**

No significant differences were appreciated between groups based on age ($P = .323, d = 0.13$) or height ($P = .098, d = 0.27$); however, the closed group was noted to be heavier.
TABLE 1
Kinematic and Kinetic Differences Between Open and Closed Pelvis Groups

| Position variables                  | Open Pelvis (n = 78) | Closed Pelvis (n = 79) | MD (95% CI)   | Cohen d | P       |
|-------------------------------------|----------------------|------------------------|---------------|---------|---------|
| Pelvic rotation at FC, deg          | 53 ± 7               | 72 ± 7                 | −19.48 (−21.69 to −17.28) | 2.78b   | <.001   |
| Stride length, %BH                  | 81 ± 5               | 77 ± 5                 | 3.80 (2.19 to 5.46)     | 0.74    | <.001   |
| Lead knee flexion FC, deg           | 49 ± 6               | 47 ± 10                | 2.71 (0.08 to 5.33)     | 0.33    | .043    |
| Lead knee extension, deg            | 20 ± 15              | 7 ± 16                 | 13.05 (8.19 to 17.91)   | 0.85b   | <.001   |
| Peak velocities                     |                      |                        |               |         |         |
| Lead knee extension, deg/s          | 424 ± 158            | 325 ± 142              | 98.61 (51.32 to 145.91) | 0.66    | <.001   |
| Pelvic rotation, deg/s              | 680 ± 93             | 666 ± 93               | −14.59 (−43.84 to 14.72) | 0.16    | .328    |
| Ball velocity, m/s                  | 39.1 ± 1.7           | 38.4 ± 2.1             | 0.66 (0.07 to 1.25)     | 0.35    | .029    |
| Kinetics                            |                      |                        |               |         |         |
| Elbow varus torque, %DW×BH          | 87.8 ± 14.7          | 90.5 ± 17.2            | −2.59 (−7.63 to 2.45)   | 0.16    | .311    |
| Elbow varus torque, %DW×BH × MER    | 5.2 ± 0.7            | 5.1 ± 1.0              | −0.06 (−0.21 to 0.33)   | 0.07    | .654    |

Data are reported as mean ± SD unless otherwise indicated. Bolded P values indicate statistically significant difference between groups (P < .05). BH, body height; BW, body weight; CI, confidence interval; FC, foot contact; MD, mean difference.

Cohen d > 0.80, denoting large effect size.

For lead knee flexion, there was a Group by Time Point interaction (P ≤ .01, partial η² = 0.13) (Figure 2). Post hoc analyses revealed that lead knee flexion was significantly greater in the open versus the closed group at foot contact (49° ± 6° vs 47° ± 10°, respectively; P ≤ .05). However, lead knee flexion was greater in the closed versus the open group at maximal external rotation (47° ± 14° vs 39° ± 12°, respectively; P ≤ .001), ball release (40° ± 17° vs 30° ± 17°, respectively; P ≤ .001), and maximal internal rotation (32° ± 19° vs 20° ± 19°, respectively; P ≤ .001) (Figure 2). In the closed group, lead knee flexion remained the same from foot contact to maximal external rotation (0° ± 1°), after which these pitchers extended their knee to maximal internal rotation (15° ± 1°). In the open group, lead knee flexion decreased from foot contact to maximal internal rotation (29° ± 2°).

There were 3 moderate negative relationships between pelvic rotation at foot contact and stride length (rₛ = −0.385, P < .001), lead knee extension (rₛ = −0.429, P < .001), and peak lead knee extension velocity (rₛ = −0.359, P < .001). Additionally, we observed a moderate correlation between lead knee extension and ball velocity (rₛ = 0.342, P < 0.001). There were no significant relationships identified for ball velocity (rₛ = −0.149, P = .063), peak pelvic rotation velocity (rₛ = 0.137, P = .86), or elbow varus torque (rₛ = 0.103, P = .201) to pelvic rotation at foot contact.

DISCUSSION

In the present study, pitchers landing with an open or closed pelvis exhibited different mechanics throughout the pitch. Pitchers with an open pelvis threw with significantly greater ball velocity (39.1 vs 38.4 m/s, P = .029), disproving our original hypothesis, in which a previous investigation theorized that landing with an open pelvis limited effective energy transfer.6 Pitchers with an open pelvis demonstrated longer stride length (81%BH vs 77%BH, P < .001), landed with greater lead knee flexion (49° vs 47°, P

Figure 2. Lead knee flexion during selected phases of the pitch delivery for the open versus closed groups. BR, ball release; FC, foot contact; MER, maximal external rotation; MIR, maximal internal rotation. *Statistically significant Group × Time Point interaction (P < .05). When compared with the open group (P = .012, d = 0.41), mean pelvic rotation for the open group was 53° ± 7° (greater pelvic rotation toward home plate) and the closed group was 72° ± 7° (rotated away from home plate) (P < .001, d = 2.78) (Table 1). The open group had faster ball velocity (39.08 ± 1.67 m/s) compared with the closed group (38.42 ± 2.06 m/s) (P = .029, d = 0.35). Pitchers in the open group had longer stride length (P < .001, d = 0.74), landed with greater knee flexion (P = .043, d = 0.33), produced greater lead knee extension (P < .001, d = 0.85), and had faster peak lead knee extension velocity (P < .001, d = 0.66) compared with those in the closed group. There were no significant between-group differences in absolute (P = .311, d = 0.16) or normalized elbow varus torque (P = .654, d = 0.07).
Pitchers landing with an open pelvis landed with greater lead knee flexion and then extended their knee a greater distance throughout the pitch when compared with pitchers with a closed pelvis. Greater lead knee extension through the pitch is thought to drive the pelvis into rotation and aid in greater transfer of energy to the pelvis and trunk. However, Wight et al reported no significant differences between early and late pelvic rotation groups in lead flexion at foot contact and ball release. While the previous study did not calculate lead knee extension, based on calculations from data provided from their investigation, early rotators extended their knee from foot contact to ball release 1.7°, compared with late rotators who actually flexed their knee 1.2°. This is significantly lower than the reported knee extension in the current study. Previous studies analyzing collegiate pitchers reported that higher velocity pitchers demonstrated greater knee extension during the pitch when compared with lower velocity pitchers. Similar findings have been reported in javelin throwing where throwers who had faster release velocity demonstrated increased knee extension. Lead knee extension has been reported to be greater in professional pitchers when compared with college pitchers, suggesting more skilled players utilize extension during the pitch, which aids in increased ball velocity. Moreover, Werner et al reported higher ball velocity was associated with more lead knee extension in collegiate pitchers. In the current study, pitchers in the open group had faster ball velocity and greater lead knee extension. When looking at all players, we observed a moderate correlation between lead knee extension and ball velocity (r = .342), suggesting that lead knee extension helps brace and stabilize the leg, allowing for the trunk to rotate and transfer energy to the throwing arm and ball. However, further investigations verifying the exact role of knee flexion and extension on appropriate energy transfer are necessary.

DURING THE PITCH, PROPER POSITIONING OF THE LOWER EXTREMITIES AND THE TRUNK ARE THE PRIMARY FORCE GENERATORS DURING THE INITIATION OF A PITCH. Increased knee extension and pelvic rotational velocities have been reported to increase the transfer of energy to the trunk and throwing arm, ultimately producing greater ball velocity. In the current study, the open pelvis group had faster lead knee extension velocity; however, no differences in peak pelvic rotational velocity between the 2 groups were observed. Similarly, Luera et al reported no significant difference in pelvic rotation velocity between high velocity and low velocity professional pitchers. While increased rotational velocities are essential to developing optimal ball velocity, proper sequencing of the velocities needs to be maintained to allow for the future evaluation of the timing of peak velocities and its influence on energy transfer during the pitch.

The increased energy transfer to the throwing arm may be beneficial in increasing ball velocity; however, we speculated it is possible that the increase in energy could also increase joint loading and torque across the elbow, potentially leading to injury and time lost from play. Within an individual pitcher, increased ball velocity has been shown to sustain increased elbow varus torque. In the current study, there was no difference in elbow varus torque between the 2 groups and there was a weak, nonsignificant correlation (r = 0.103, P = .201) when elbow varus torque
was examined against pelvic rotation at foot contact. Conversely, Wight et al\textsuperscript{19} reported a strong negative correlation between pelvic rotation and elbow varus torque ($r_s = -0.76$, $P < .05$) in high school and collegiate players. These conflicting results could be attributed to differences in the study populations. Professional pitchers have been shown to transfer momentum up the kinetic chain more efficiently, while producing greater ball velocity and limiting torque placed at the elbow. Further investigation is warranted to examine the effects of pelvic deficiencies in professional pitchers and their relation to increased torque and injury.

Limitations

This study had limitations. Professional level at the time of evaluation (Major League vs Minor League) was not analyzed given the highly transient nature with which pitchers are moved based on performance, roster moves, injuries, etc. Only professional pitchers were used in this study; thus the results are not generalizable to non-elite pitchers participating in various levels of competition. Younger, less experienced pitchers are generally smaller, with less strength, resulting in different mechanics during throwing motion that are generally not seen in professional pitchers.\textsuperscript{18,20} Moreover, potentially confounding variables related to handedness, trunk and throwing arm kinematics, previous injury or surgical history, and workload were not accounted for in our analyses and could influence the findings. While pitchers were instructed to pitch with game-like effort and threw from the mound, this controlled setting was atypical from practice and competition, and it is possible pitchers may have pitched with reduced effort. Only fastballs were used in this analysis; therefore, the findings may not be applicable to other pitch types. Pelvic rotation was investigated only at foot contact; however, this is a continuous variable, and the influence on ball velocity, as well as throwing arm kinetics, is uncertain at other timepoints. Finally, we did not investigate within-pitcher effects of pelvic rotation styles, and changes within a pitcher might result in different outcomes.

CONCLUSION

In this study, professional pitchers who landed with an open pelvis demonstrated longer stride length, greater lead knee extension, faster lead knee and trunk velocities, as well as faster ball velocities compared with pitchers with a closed pelvis. This increase in segment velocities and ball velocities was not associated with an increase in elbow varus torque and displays a potentially efficient method of increasing ball velocity without an increase in elbow varus torque.

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