

Correlation of Shoulder and Elbow Kinetics With Ball Velocity in Collegiate Baseball Pitchers

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Context: Throwing a baseball is a dynamic and violent act that places large magnitudes of stress on the shoulder and elbow. Specific injuries at the elbow and glenohumeral joints have been linked to several kinetic variables throughout the throwing motion. However, very little research has directly examined the relationship between these kinetic variables and ball velocity.

Objective: To examine the correlation of peak ball velocity with elbow-valgus torque, shoulder external-rotation torque, and shoulder-distraction force in a group of collegiate baseball pitchers.

Design: Cross-sectional study.

Setting: Motion-analysis laboratory.

Patients or Other Participants: Sixty-seven asymptomatic National Collegiate Athletic Association Division I baseball pitchers (age = 19.5 ± 1.2 years, height = 186.2 ± 5.7 cm, mass = 86.7 ± 7.0 kg; 48 right handed, 19 left handed).

Main Outcome Measure(s): We measured peak ball velocity using a radar gun and shoulder and elbow kinetics of the throwing arm using 8 electronically synchronized, high-speed digital cameras. We placed 26 reflective markers on anatomical landmarks of each participant to track 3-dimensional coordinate data. The average data from the 3 highest-velocity

fastballs thrown for strikes were used for data analysis. We calculated a Pearson correlation coefficient to determine the associations between ball velocity and peak elbow-valgus torque, shoulder-distraction force, and shoulder external-rotation torque ($P < .05$).

Results: A weak positive correlation was found between ball velocity and shoulder-distraction force ($r = 0.257$; 95% confidence interval [CI] = 0.02, 0.47; $r^2 = 0.066$; $P = .018$). However, no significant correlations were noted between ball velocity and elbow-valgus torque ($r = 0.199$; 95% CI = -0.043 , 0.419; $r^2 = 0.040$; $P = .053$) or shoulder external-rotation torque ($r = 0.097$; 95% CI = -0.147 , 0.329; $r^2 = 0.009$; $P = .217$).

Conclusions: Although a weak positive correlation was present between ball velocity and shoulder-distraction force, no significant association was seen between ball velocity and elbow-valgus torque or shoulder external-rotation torque. Therefore, other factors, such as improper pitching mechanics, may contribute more to increases in joint kinetics than peak ball velocity.

Key Words: throwing athletes, upper extremity, torque, force

Key Points

- A weak positive correlation was observed between ball velocity and shoulder-distraction force.
- No association was noted between ball velocity and elbow-valgus torque or shoulder external-rotation torque.
- Improper pitching mechanics may contribute more than ball velocity to increases in joint kinetics.

Injury rates among baseball pitchers at all levels of competition are on the rise, and the elbow and shoulder are the most commonly injured joints.^{1–4} With approximately 27 000 to 45 000 collegiate players and more than 4.5 million total participants in organized baseball in the United States each year, finding ways to reduce the incidence of injury should be a primary objective of sports medicine professionals working with baseball players.^{5–7}

Specific injuries at the elbow and glenohumeral joints have been linked to several kinetic variables during the throwing motion. Medial elbow injuries, such as ulnar collateral ligament sprains, are often caused by excessive elbow valgus and shoulder external-rotation torques occurring during the late cocking phase of throwing.^{8–16} At the glenohumeral joint, that external-rotation torque during the late cocking phase and distraction forces during the deceleration phase are theorized to contribute to tears of

the labrum.^{9,11,17,18} Additionally, the peak distraction force generated during the arm-deceleration phase may contribute to rotator cuff injuries.^{9,11,17,19–22}

Previous researchers have linked elbow and shoulder injuries to a variety of risk factors, including pitch volume,^{23,24} increased innings pitched in a calendar year,^{23,25} increased body mass,²³ pitch type,^{24,26,27} and number of months pitched per year.²³ More recently, ball velocity has been examined as a possible risk factor for injury.^{10,23,28–30} Increased ball velocity has been identified as a risk factor for elbow and shoulder injury in adolescent pitchers²⁷ and for elbow injury in professional baseball pitchers.^{23,28} Hurd et al²⁹ found a positive association between pitch velocity and elbow-varus moments in a group of high school pitchers. However, this was a nonelite sample of pitchers, and no authors have directly examined the relationship between ball velocity and the kinetic variables that have been implicated as contributing to

Table. Correlation of Kinetic Variables With Ball Velocity

Variable	Mean \pm SD	<i>r</i>	<i>r</i> ²	<i>P</i> Value
Elbow-valgus torque (% body weight \times height)	5.7 \pm 1.3	0.199	0.040	.053
Shoulder-distraction force (% body weight)	110.0 \pm 16.0	0.257	0.066	.018 ^a
Shoulder external-rotation torque (% body weight \times height)	5.2 \pm 1.0	0.097	0.009	.217

^a Significant correlation ($P < .05$).

injuries at the elbow and shoulder in pitchers at higher levels of competition. A strong association between ball velocity and joint kinetics might indicate that throwing at higher velocities puts more stress on joints, and, as a result, participants who throw at higher velocities are at an increased risk for injury. However, no association between ball velocity and joint kinetics would indicate that other variables besides ball velocity could be manipulated to alter joint kinetics and reduce injuries. Therefore, the purpose of our study was to examine the correlation of ball velocity with elbow-valgus torque, shoulder-distraction force, and shoulder external-rotation torque in a group of National Collegiate Athletic Association (NCAA) Division I collegiate baseball pitchers. Our hypothesis was that ball velocity would have a moderate positive correlation with elbow-valgus torque, shoulder-distraction force, and shoulder external-rotation torque.

METHODS

Participants

A total of 67 NCAA Division I collegiate baseball pitchers (age = 19.5 \pm 1.2 years, height = 186.2 \pm 5.7 cm, mass = 86.7 \pm 7.0 kg; 48 right handed, 19 left handed) volunteered to participate in this study. Exclusion criteria were any upper or lower extremity injury within the previous 3 months or any history of upper or lower extremity surgery.

Procedures

Before the testing session in the motion-analysis laboratory, each participant provided informed consent as required by the institutional review board, which also approved the study. In addition, we recorded height, mass, radius length, humerus length, and medical history.

Participants then completed their preferred warm-up routines. The routines were not standardized but generally consisted of various static and dynamic stretches, flat-ground throwing exercises, and pitching drills. After the warm-up, each participant had 1.2-cm-diameter spherical reflective markers (Motion Analysis Corporation, Santa Rosa, CA) placed over 26 anatomical landmarks to record motion-capture data.^{18,31,32} Markers were placed bilaterally at the lateral tip of the acromions, lateral humeral epicondyles, anterior-superior iliac spines, base of the sacrum, medial and lateral epicondyles of the femurs, medial and lateral malleoli, calcanei, radial and ulnar styloids, third metacarpal of the throwing arm, and between the second and third metatarsal heads. Each participant wore a hat with markers placed on the left side, right side, and top of the head. The markers were secured with electrode collars and tape to prevent excessive motion. Additionally, participants pitched with no shirt and while wearing spandex shorts to prevent motion of the markers.

After all the markers were secured, the participants concluded their warm-ups by throwing as many pitches as desired to acclimate themselves to the indoor testing facility.

For data collection, participants pitched from a regulation collegiate indoor pitching mound (Osborne Innovative Products, Inc, Jasper, IN). Each player threw fastballs off the mound toward a regulation-distance (18.4 m) strike-zone target. Testing concluded once the pitcher had thrown 5 representative fastball trials, excluding pitches thrown out of the strike zone and pitches that the player determined did not represent his typical throwing mechanics. An investigator stood directly behind the strike-zone target to record pitch location and measure ball velocity using a radar gun (Stalker Radar, Plano, TX). The average of the 3 highest-velocity fastballs thrown for strikes was used for data analysis.

Each pitch was recorded using 8 electronically synchronized, high-speed (240 Hz) Eagle digital cameras (Motion Analysis Corporation). ExpertVision software (Eva 6.0; Motion Analysis Corporation) was used to track the reflective markers, and 3-dimensional coordinate data were determined via direct linear transformation. Joint centers of the shoulder and elbow for the throwing and nonthrowing arm were estimated using previously described methods.¹² Data were filtered with a Butterworth fourth-order, zero-lag digital filter (cutoff = 10 Hz). Kinetic data at the elbow and shoulder were calculated using methods described by Feltner and Dapena.³³ Force was expressed as percentage of body weight and torque was expressed as a percentage of body weight \times height to normalize data for between-subjects comparisons. The peak value for each variable (elbow-valgus torque, shoulder-distraction force, and shoulder external-rotation torque) was identified by averaging the peak values from the 3 highest-velocity fastball trials.

Data Analysis

We generated a Pearson correlation coefficient to determine the relationship between ball velocity and peak elbow-valgus torque, shoulder-distraction force, and shoulder external-rotation torque. Statistical testing was performed with SPSS statistical software (version 20.0; IBM Corp, Armonk, NY). Statistical significance was established a priori at $P < .05$.

RESULTS

Mean and standard deviation values for the group were a ball velocity of 37.3 \pm 1.6 m/s (83.5 \pm 3.5 mph), elbow-valgus torque of 5.7% \pm 1.3% (body weight \times height), shoulder-distraction force of 110.0% \pm 16.0% (body weight), and shoulder external-rotation torque of 5.2% \pm 1.0% (body weight \times height).

The results of the correlation analyses are displayed in the Table. We found a weak positive correlation between ball velocity and shoulder-distraction force ($r = 0.257$; 95% confidence interval [CI] = 0.02, 0.47; $r^2 = 0.066$; $P = .018$). However, no significant correlations were observed between ball velocity and elbow-valgus torque ($r = 0.199$; 95% CI = -0.043, .419; $r^2 = 0.040$; $P = .053$) or ball velocity and shoulder external-rotation torque ($r = 0.097$; 95% CI = -0.147, 0.329; $r^2 = 0.009$; $P = .217$).

DISCUSSION

Contrary to our hypothesis, we noted only a weak positive correlation between ball velocity and shoulder-distraction force. Additionally, simple linear regression revealed very small r^2 values (Table), indicating that very little of the variance in joint kinetics can be explained by ball velocity. The correlations between ball velocity and both elbow-valgus torque and shoulder external-rotation torque were not significant. These results differ from what has previously been reported²⁹ and indicate that variables other than simply throwing at a high velocity are contributing to elbow and shoulder kinetics.

The concept that many variables contribute to more or less efficient pitching mechanics and alter forces at the elbow and shoulder is well supported by research.^{18,34-39} Some of these variables include the timing of trunk rotation, timing between phases of the pitching motion, and degree of shoulder external rotation, elbow flexion, and shoulder abduction at stride-foot contact.^{34,35,37,38} Oyama et al³⁶ found that pitchers who exhibited excessive contralateral trunk tilt during the pitching motion had increased elbow proximal force, shoulder proximal force, elbow-varus moment, and shoulder internal-rotation moment.³⁶ Interestingly, pitchers with excessive contralateral trunk tilt also threw with greater ball velocity, but those increases in velocity were not correlated with any kinetic variables except shoulder proximal force.³⁶ Similarly, our results showed no significant correlations between pitch velocity and any kinetic variables except shoulder-distraction force. Werner et al¹⁸ identified 10 kinematic and kinetic variables that accounted for 89% of the variance in shoulder-distraction force.¹⁸ Finally, Davis et al³⁹ identified 5 pitching mechanical factors that, when successfully performed, led to decreases in humeral internal-rotation torque and elbow-valgus load.³⁹ Pitchers of all ages should be instructed in these more efficient mechanics with the goals of improving performance and reducing the risk of injury.

Several studies^{23,28} appear to link higher ball velocities with injury risk. Bushnell et al²⁸ found a significant association between increased ball velocity and risk for elbow injury in professional baseball pitchers.²⁸ Additionally, Olsen et al²³ described increased ball velocity as one of many risk factors for elbow and shoulder injuries in adolescent pitchers. However, the increased risk seen in these studies may have been due to other factors, such as the fact that pitchers who throw with greater ball velocity have a competitive advantage and, therefore, will throw more often than pitchers with slower fastball velocities. These pitchers may instead be at increased risk of injury because of their higher pitch volume, which has been repeatedly linked to injury in pitchers.²³⁻²⁵ Although we did not examine injury risk, our results showed little to no

association between pitch velocity and the kinetic variables that are believed to contribute to injuries at the elbow and shoulder.

These findings are contrary to much of the previous research regarding ball velocity and joint kinetics. Fleisig et al¹⁰ found that as pitchers went from partial-effort to full-effort throwing and increased their ball velocity, several kinetic variables (including elbow-varus torque, shoulder internal-rotation torque, and shoulder-compressive force) also increased.¹⁰ However, they reported that several kinematic variables changed as well: maximum glenohumeral external rotation during the late arm-cocking phase and elbow-flexion angle at the moment of stride-foot contact. These alterations in motion lead to the question of whether the increases in the shoulder and elbow forces are a result of the increased ball velocity, altered kinematics, or both. In a separate study, Fleisig et al¹² showed that elbow-varus torque, shoulder internal-rotation torque, and shoulder-compressive force increased, along with ball velocity, as competition level increased.¹² However, kinematic differences were present among competition levels, including elbow-flexion angle at stride-foot contact and maximum elbow-extension velocity during the arm-acceleration phase. The differences observed by Fleisig et al¹² in ball velocity and joint kinetics and kinematics among competition levels support the weak correlation seen in our study between ball velocity and joint kinetics. To our knowledge, Hurd et al²⁹ performed the only direct examination of the relationship between ball velocity and kinetics across participants at a similar competitive level. Their results showed that increased ball velocity was positively associated with increased adduction (varus) moments at the elbow in high school pitchers.²⁹ Conversely, our results did not reveal a statistically significant association between pitch velocity and elbow-valgus torque in elite collegiate baseball pitchers. This may be due to differences in the study populations. Our sample of elite Division I collegiate baseball pitchers may have used some of the more efficient mechanics described earlier and, thus, were able to throw at higher velocities than the high school pitchers without increasing the forces at their joints. Our findings may also indicate a survival effect among our elite pitchers compared with high school pitchers. Pitchers who threw at lower velocities or were unable to throw at higher velocities without increasing the forces on their joints may not have advanced to an elite level because of injury or ineffectiveness. Additionally, the disagreement between our results and those of Hurd et al²⁹ may reflect confounding variables that went unidentified in both studies and could be influencing the relationships between ball velocity and joint kinetics. These variables may include factors such as alterations in proximal-to-distal-segment sequencing and timing between the pitchers in our sample and those at the high school level. These differences in segment sequencing and timing may have led to differences in ball velocity and joint kinetics between the groups.

Several limitations to our study are worth noting. Kinetic calculations are based in part on estimated body-segment masses of cadavers, which may not accurately represent the body-segment masses of the young, asymptomatic participants we examined. Also, an unavoidable amount of skin movement occurred where each reflective marker was placed. However, we tried to minimize this movement, as

did numerous previous authors^{8,12,29–31,34,37} who used the same technique. It is also interesting to note that our mean value for shoulder-distraction force was higher than had been previously reported.¹⁸ Werner et al¹⁸ found an average peak shoulder-distraction force value of 81 ± 10 (% body weight) in a group of 48 collegiate baseball pitchers compared with our value of 110.0 ± 16.0 (% body weight). However, this difference may simply be attributable to differences in participants, as Werner et al¹⁸ recruited from all divisions of NCAA collegiate baseball and not only Division I, as we did. Furthermore, we examined only asymptomatic pitchers, which limits the conclusions that can be inferred about injured pitchers. In addition, the results of this study may not apply to youth, adolescent, or professional pitchers.

CONCLUSIONS

We observed little association between ball velocity and several kinetic variables at the elbow and shoulder joints in Division I collegiate baseball pitchers. Although a weak positive correlation was seen between ball velocity and shoulder-distraction force, no significant association was seen between ball velocity and elbow-valgus torque or shoulder external-rotation torque. Therefore, factors other than ball velocity, such as certain kinematic variables (eg, segment sequencing and timing), may contribute more significantly to increases in joint kinetics. Future studies are necessary to determine which mechanics are most effective in minimizing kinetic loads at the elbow and shoulder.

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