# Correlation of Throwing Mechanics With Elbow Valgus Load in Adult Baseball Pitchers

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**Background:** Studies have shown that various biomechanical factors affect valgus extension overload during baseball pitching; yet, their relationships are not clearly defined, and factors such as trunk rotation and arm slot have not been investigated.

**Hypothesis:** The onset of trunk rotation, with other biomechanical variables that define sequential body motion, will significantly predict elbow valgus loading.

**Study Design:** Descriptive laboratory study.

**Methods:** Sixty-nine adult baseball players pitched off an indoor mound during 3-dimensional motion analysis to measure whole body kinematics and kinetics at 240 Hz. Thirteen biomechanical variables were calculated and extracted for regression analysis to investigate their associations with elbow valgus load. A 2-way analysis of variance compared valgus torques between pitchers with 2 onsets of trunk rotation (before and after front-foot contact) and 2 arm slot positions (overhand and sidearm).

**Results:** Six biomechanical variables had significant correlations ($P < .02$) with elbow valgus torque—with maximum shoulder external rotation, elbow flexion at peak valgus torque, and elbow valgus loading rate accounting for 68% of its variance. Reduced elbow valgus torques were associated with increased elbow flexion ($P < .01$). Players who initiated trunk rotation before front-foot contact had significantly higher elbow valgus torques than did those who rotated afterward ($P = .02$). Fourteen pitchers displayed a sidearm delivery and had significantly higher elbow valgus torques than did those with an overhand arm slot position.

**Conclusion:** Valgus torque at the elbow during baseball pitching is associated with 6 biomechanical variables of sequential body motion. A condition of late trunk rotation, reduced shoulder external rotation, and increased elbow flexion appeared to be most closely related to valgus torque. Sidearm pitchers appeared to be more susceptible than overhand pitchers to reduced elbow valgus torque.

**Clinical Relevance:** The biomechanical findings of this study offer scientific feedback for developing methods used to minimize the effects of valgus load on pitching-related elbow injuries.

**Keywords:** pitching mechanics; kinetics; kinematics; elbow; torque; force; valgus

Researchers generally believe that increased stresses at the throwing arm contribute to the increasing incidence of overuse injuries in baseball. In particular, youth and adult pitchers' elbow injuries have reportedly been linked to the physiological effects of these joint stresses as brought about from excessive valgus loading at the throwing elbow.[5,12,21] Thus, determining the biomechanical patterns that place the elbow at higher risk may lead to coaching and training methods designed to correct inefficient pitching mechanics that lead to high valgus loads. These kinematic and kinetic parameters indicate the patterns in sequential body motion that influence the pitch as well as the joint-reaction forces at the elbow. As such, efficient throwing mechanics is predicated on a pitcher's ability to perform a sequence of movements in body segments, which progresses from the legs, pelvis, and trunk to the smaller distal arm segments.[3,9,13,15]

One important aspect of efficient sequential body motion is arm slot position before ball release, which is the vertical-horizontal position of the throwing extremity during the delivery. This position is kinematically determined by trunk tilt, shoulder abduction, and elbow flexion, and it is believed to significantly influence the magnitude of valgus forces at the elbow. Albright et al[2] reported that 73% of the 73 pitchers in their sample exhibited symptoms of

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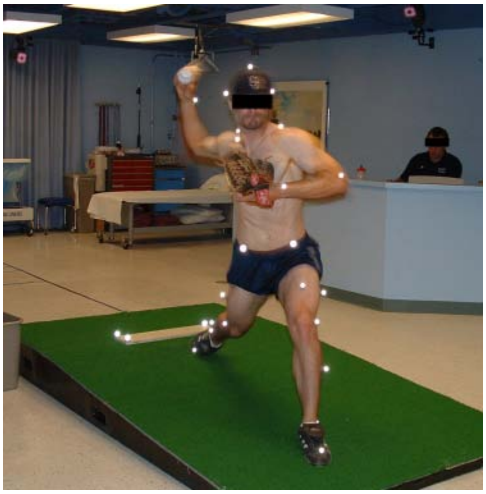

**Figure 1.** Experimental setup and participant preparation.

**Figure 2.** Elbow valgus torque was measured as the bending moment about the elbow joint that would place its lateral structures under compression and the medial aspect under tension.

elbow injury when arm slot was relatively horizontal with increased elbow flexion. The investigators observed that in extreme cases, pitchers were symptomatic when exhibiting the whipping action during throwing, most frequently seen in pitchers with a sidearm delivery. In these cases, early trunk rotation and increased elbow flexion are often involved and can perhaps lead to potentially detrimental joint stresses.[1,20] Werner et al[20] found that elbow flexion was, among other factors, a strong predictor of valgus loading but that it did not factor in timing of trunk rotation, which can indicate when a pitcher opens up.

Studies have reported that professional pitchers who rotate later in the pitching cycle generate less internal rotation torque at the shoulder than do those who rotate earlier.[1] Given that elbow valgus stress is believed to be significantly correlated with shoulder rotation torque,[8,20] we hypothesized that the onset of trunk rotation would subsequently influence elbow valgus loading, along with other kinematic patterns, such as elbow flexion. Thus, the purpose of this study was to measure the effects of sequential body motion—defined by a relevant set of kinematic and kinetic parameters—on elbow valgus torque during baseball pitching.

## MATERIALS AND METHODS

### Participant Preparation

Sixty-nine adult pitchers were recruited from collegiate (n = 58), minor league (n = 8), and major league (n = 3) teams and ultimately included in this study. Before participating, all pitchers signed written informed consent forms approved by the hospital's institutional review board. Their mean age, height, and body mass were as follows: 20 ± 2 years, 180 ± 14 cm, and 86 ± 10 kg, respectively. All pitchers were actively playing organized baseball in their respective leagues and were considered relatively healthy, with no significant bodily injury at the time of testing.

For each participant, 12.5-mm spherical reflective markers were placed on the skin, overlying 34 anatomical landmarks, to bilaterally define the hip, knee, ankle, shoulder, elbow, and wrist joints, as well as the upper and lower limb segments during 3-dimensional motion analysis of pitching (Figure 1).[1]

### Setup and Protocol

Motion capture was conducted using 8 visible-red digital cameras interfaced with the Real-Time Motion Capture System (Eagle 1M, Motion Analysis Corp, Santa Rosa, California). Strobe control was set at 240 Hz with full pixel resolution, whereas data sampling rate was fixed at 240 Hz. The average 3-dimensional residual error for the motion capture system was 0.9 ± 0.4 mm, which is the degree of accuracy in which the system can reconstruct the location of each marker in the capture volume. Marker tracks were processed using marker identification techniques and digital signal processing that incorporated a Butterworth filter at a cutoff frequency of 18 Hz. The marker-based optical system was housed in a 130-$m^2$ motion analysis laboratory with cameras positioned to allow for a calibrated volume of space, 5 × 2 × 4 m (length × width × height), for capturing throwing motion off an indoor mound, 2.7 × 2.5 × 0.3 m (length × width × height) (ProMounds Inc, Winthrop, Massachusetts). Ball velocity was monitored using a Bushnell Speedster radar gun (Bushnell Performance Optics, Lenexa, Kansas).

After performing a preparation routine of stretching and warm-up throwing, each pitcher threw up to 15 fastball pitches off the indoor mound to a simulated strike zone at a regulation distance of 18.4 m from the pitching rubber. Pitchers or their coaches were asked to rate each pitch on a scale from 1 to 5, with 1 being the worst and 5 being the

**Figure 3.** Pitching events include (as depicted from left to right) stride, front-foot contact, maximum external rotation, and ball release. The pitching cycle was normalized from front-foot contact to ball release to allow for biomechanical comparisons across all participants.

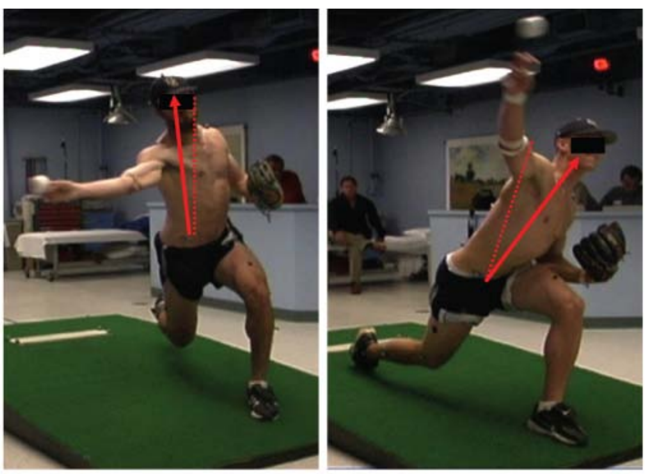

**Figure 4.** Sidearm slot position (left) and overhand, or "3/4," slot position (right) were identified by ipsilateral and contralateral trunk lean, respectively.[14]

best, using a subjective criteria of ball location and body posture at release. Three of the highest-rated pitches were analyzed for each participant; data from these pitches subsequently exhibited low within-pitcher variability (coefficient of variation <6%). Thus, the fastest pitch that hit the strike zone with reliable marker data was ultimately selected for analysis, in agreement with previous studies that employed similar methods.[14,16]

## Biomechanical Model

Local coordinate systems were defined for the trunk, upper arm, forearm, and hand segments to calculate 3-dimensional rotations at the shoulder and elbow joints, as based on previously described methods.[1] Pelvic kinematic data were calculated relative to the fixed coordinate system of the laboratory, allowing for trunk rotations to be calculated relative to the pelvis. The transverse plane rotation of the trunk relative to the pelvis provided what some baseball coaches refer to as *hip-shoulder separation*, which was considered neutral when this degree of separation was zero.

Joint torques of the throwing arm were calculated using the inverse dynamics technique described by Feltner and Dapena,[7] which estimates the forces and torques about a joint based on the kinematics of its movement and the inertial properties of adjacent segments. For the purpose of this study, only internal-external rotational torque at the shoulder and valgus torque at the elbow were analyzed. Valgus torque was defined as the bending moment about the elbow joint that would cause an increase in compressive force on the lateral structures and an increase in tensile force on the medial side (Figure 2). Inertial properties of the throwing arm segments used for this analysis were estimated using anthropometric ratios measured from adult male cadavers.[6,p59] The mass of a 23-cm circumference baseball was 0.14 kg.

To evaluate the temporal patterns across all participants, the onset of each parameter was expressed as a function of the normalized pitching cycle, defined from front-foot contact (0%) to ball release (100%), as shown in Figure 3. In particular, the onset time of trunk rotation was defined as the event in which the magnitude of trunk rotation, relative to the pelvis, begins to decrease from its maximum value[1]—or, in the words of baseball coaches, when the shoulders begin to square up toward home plate.

## Statistical Analysis

Trunk, shoulder, and elbow kinematics and kinetics were extracted for correlation analysis to evaluate the effects of various biomechanical parameters on elbow joint valgus torque. A linear stepwise multiple regression analysis was performed to investigate the relationship of 13 biomechanical parameters on elbow valgus torque and to determine an optimal set of kinematic and kinetic parameters that collectively predict elbow valgus loading.[20] These parameters included the onset of trunk rotation, trunk rotation magnitude, trunk lean, maximum shoulder external rotation, shoulder abduction, horizontal abduction, maximum elbow flexion, onset of maximum elbow flexion, elbow flexion at peak valgus torque, elbow flexion at ball release, maximum horizontal adduction velocity, and valgus loading rate. Those parameters that showed statistically significant correlations ($\alpha = .05$) with elbow valgus torque were identified and selected as independent variables in the regression model. In addition, a 2-way analysis of

TABLE 1
Demographic Information for Participant Pitchers, by Trunk Rotation and Arm Slot Position

| Group | n | Age, years | Height, cm | Weight, kg | Ball Speed, m/s |
|---|---|---|---|---|---|
| Onset of trunk rotation | | | | | |
| Pre–foot contact | 34 | 20.3 ± 2.5 | 177.0 ± 15.0 | 86.5 ± 9.3 | 33.1 ± 4.1 |
| Post–foot contact | 35 | 20.9 ± 2.4 | 185.0 ± 6.4 | 85.6 ± 10.3 | 31.8 ± 1.6 |
| Arm slot position | | | | | |
| Sidearm | 14 | 21.1 ± 3.0 | 181.0 ± 12.7 | 87.0 ± 10.0 | 30.8 ± 1.2 |
| Overhand | 55 | 20.7 ± 2.5 | 175.2 ± 16.1 | 85.9 ± 9.8 | 33.0 ± 2.9 |

TABLE 2
Kinematic and Kinetic Parameters With Significant Correlations With Elbow Valgus Torque[a]

| Parameter | Mean ± SD | *r* | *P* |
|---|---|---|---|
| Onset of trunk rotation, % PC | –1 ± 28 | –.24 | .019 |
| Max shoulder external rotation, deg | 169 ± 15 | .60 | .000 |
| Max elbow flexion time, % PC | 51 ± 23 | –.32 | .012 |
| Elbow flexion at peak valgus, deg | 43 ± 22 | –.36 | .004 |
| Elbow flexion at ball release, deg | 41 ± 24 | –.35 | .005 |
| Valgus loading rate, N·m/s | 29 ± 14 | .74 | .000 |

[a]PC, pitching cycle.

variance was performed on elbow valgus torque using 2 onset times of trunk rotation (pre–foot contact versus post–foot contact) and arm slot position (overhand versus sidearm) using contralateral trunk lean as criteria.[14] Those pitchers whose contralateral trunk lean was zero or negative, indicating a trunk lean ipsilateral to the throwing arm, were considered to have a sidearm slot position (Figure 4). Because no significant interaction between the 2 factors was found ($P = .84$), data from all pitchers with pre–foot contact onset times were compared with data of those with post–foot contact times, regardless of arm slot position. Similarly, data from all overhand pitchers were compared with those of sidearm pitchers. Differences in the data from the 2 comparisons were considered significant at less than the adjusted alpha level of .03. Table 1 lists demographic information, sample size, and mean ball velocity for each group.

## RESULTS

The mean elbow valgus torque on the throwing arm across all participants was 50 ± 29 N·m. Six kinematic and kinetic parameters were found to have significant correlations with elbow valgus torque (Table 2). However, elbow valgus torque was most significantly influenced by 3 parameters—maximum shoulder external rotation, elbow flexion at peak valgus torque, and elbow valgus loading rate—which accounted for 68% of the variance in valgus torque. Mean values in maximum shoulder external rotation, elbow flexion at peak valgus torque, and valgus loading rate, along with

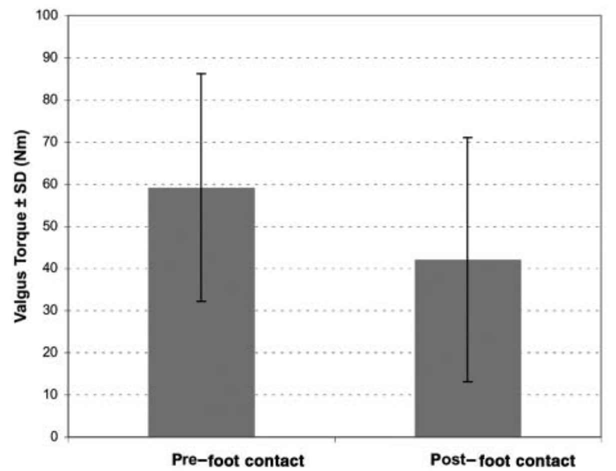


**Figure 5.** Mean elbow valgus torque for pitchers with onset times of trunk rotation before front-foot contact (pre–foot contact) was significantly higher ($P$ = .02) than that of pitchers with onsets after front-foot contact (post–foot contact).

correlations with elbow valgus torque, were as follows, respectively: 169° ± 15° ($r = .60$, $P < .01$), 41° ± 24° ($r = –.36$, $P < .01$), and 29 ± 14 N·m ($r = .74$, $P < .01$). In addition, trends in the sample data indicated that elbow valgus correlated with maximum contralateral trunk lean ($r = .22$, $P = .06$) and shoulder abduction ($r = –.23$, $P = .06$).

The analysis of variance performed to determine the effects of the timing of trunk rotation and arm slot position on elbow valgus torque revealed no significant interaction between the 2 factors ($P = .84$). Thus, subsequent between-group analysis revealed that 34 of the 69 pitchers included in the sample initiated trunk rotation before front-foot contact, whereas 35 did so afterward (Table 1). Although there were no significant differences in demographics or ball velocity between groups ($P > .10$), the pre–foot contact players exhibited significantly more elbow valgus torque (59 ± 27 N·m) than the post–foot contact players did (42 ± 29 N·m, $P = .02$) (Figure 5). Fourteen pitchers displayed a sidearm delivery, exhibiting an average elbow valgus torque of 66 ± 24 N·m, which was significantly higher ($P = .02$) than that of those who threw with the more common overhand, or "3/4," slot position (46 ± 29 N·m) (Figure 6).

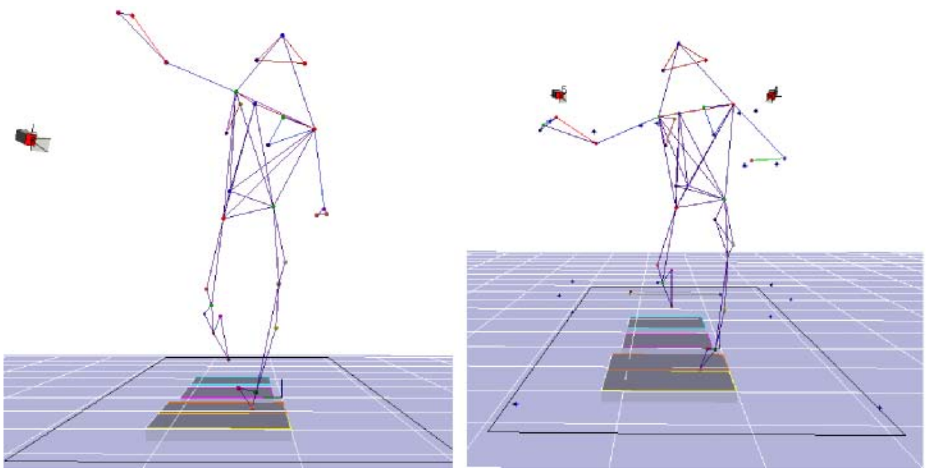

**Figure 6.** Pitchers who threw with a 3/4, or overhand, slot position (left) exhibited significantly less elbow valgus torque (46 ± 29 N·m, $P$ = .02) than did those with a sidearm delivery (right) (66 ± 24 N·m).

## DISCUSSION

The high incidence of elbow injuries that occurs among baseball pitchers has been presumably linked to the bending moment induced during throwing that places the elbow joint under excessive valgus load.[4,8,17,21] To identify the pathomechanics of valgus extension overload, we investigated the kinematic and kinetic patterns in joint movement during baseball pitching in predicting elbow valgus torque. The results of this study indicate that elbow valgus torque is most influenced by maximum shoulder external rotation, elbow flexion at peak valgus load, elbow flexion at ball release, timing of maximum elbow flexion, onset of trunk rotation before ball release, and elbow valgus loading rate. Although regression analysis does not determine whether elbow valgus torque is directly caused by these factors, the probability of predicting it based on these parameters is high. These kinematic and kinetic patterns reinforce previously published findings indicating that elbow valgus torque is closely related to angular mechanics at the shoulder and elbow during pitching; therefore, determining their relationships with elbow valgus torque provides further insight into the ways of perhaps reducing excessive valgus loading.[4,11,19,20]

Elbow valgus torque increased with greater degrees of shoulder external rotation but decreased with more elbow flexion at ball release. Although higher shoulder external rotation is expected to increase elbow valgus,[8,17] the findings of this study challenge the commonly held belief of pitching coaches that the elbow should be straighter during the delivery.[2] Specifically, this study showed that an increase in elbow valgus torque was associated with decreased elbow flexion. Similarly, a higher elbow flexion angle at the instant of peak elbow valgus was associated with reduced magnitudes of elbow valgus torque. Previous investigators found a similar relationship but did not offer suggestions of why it contradicts the teaching principles of most pitching instructors.[11,20] Although less elbow flexion would seemingly reduce the moment arm about the long axis of the humerus and subsequently minimize elbow valgus loading, the moment arm about the trunk's axis of rotation as it squares up increases with elbow extension. The extended elbow induces a bending moment at the elbow as the throwing arm lags behind in the early part of acceleration, particularly in instances when the shoulder is abducted at or near 90°.[1,2,14] The exact contribution of the moment about the trunk versus that of the moment about the humerus in directly influencing elbow valgus loading warrants further investigation. However, the moment about the trunk's axis of rotation could arguably be greater than the moment about the humeral long axis (produced by a more flexed elbow) owing to higher segmental moments of inertia and the lever arm away from the trunk. Thus, valgus torques were reduced with shorter lever arms away from the rotating trunk in a more flexed elbow and were increased with longer lever arms.

Greater segmental moments of inertia would equate to higher joint torques, as demonstrated in previous studies that compared adult pitchers and younger pitchers.[1,10] However, in this study, pitchers from all 4 groups were similar in size and ball velocity, yet elbow valgus torque was higher in the pre–foot contact and sidearm groups than in the groups of their respective counterparts. Thus, a potential measure of pitching efficiency could be described by a ratio of ball velocity to valgus torque where a highly efficient pitcher is one who can maximize output (ball speed) with the least cost (joint load). How a pitcher delivers a pitch with high efficiency is predicated on the biomechanical factors described in this study, as well as on those that have been shown to be associated with ball velocity[18] and elbow valgus torque.[14,17,20]

Pitchers who rotated their trunks (ie, squared up) later in the pitching cycle appeared to have reduced magnitudes of elbow valgus torque. In this study, pitchers who initiated trunk rotation before front-foot contact exhibited significantly more elbow valgus torque than did those who rotated their trunks afterward. This finding concurs with previously reported findings that showed reduced shoulder rotation torques in pitchers with late trunk rotation,[1] and it supports the notion that efficient mechanics is predicated on the appropriate timing in the sequence of pelvis, trunk, and arm rotations.[3,9,13,15] Although it is unclear when exactly the optimal point is in the pitching cycle for the trunk to initiate its rotation toward home plate, most pitching coaches believe that it should not occur before the front foot contacts the mound.

This study showed a tendency for higher elbow valgus torques with lower shoulder abduction angles. Thus, in sidearm deliveries, the whipping action that results from early trunk rotation may exacerbate higher valgus loads as the horizontally placed arm lags behind into ball release. The horizontal arm slot position—as determined by trunk lean, shoulder abduction, and elbow flexion—has been shown to be associated with increased medial elbow forces.[1,2,14] These findings indicated that pitchers who displayed a sidearm delivery exhibited elbow valgus torques significantly higher than those of pitchers who threw with the more common 3/4, or overhand, slot position, thereby corroborating previous suggestions that valgus forces at the elbow would be least at more vertical slot positions.[1,2,14]

In conclusion, biomechanical predictors of valgus extension torque at the elbow have been described. A condition of late trunk rotation, reduced shoulder external rotation, and increased elbow flexion appeared to be associated with reduced elbow valgus torque. Although a number of intrinsic and extrinsic factors are involved in pitching-related elbow injuries, these biomechanical findings offer additional scientific feedback for developing methods used to minimize the effects of valgus loading on these injuries.

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