# A Biomechanical Comparison of the Fastball and Curveball in Adolescent Baseball Pitchers

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**Background:** The incidence of shoulder and elbow injuries in adolescent baseball players is rapidly increasing. One leading theory about this increase is that breaking pitches (such as the curveball) place increased moments on the dominant arm and thereby increase the risk of injury.

**Hypothesis:** There is no difference in the moments at the shoulder and elbow between fastball and curveball pitches in adolescent baseball pitchers.

**Study Design:** Controlled laboratory study.

**Methods:** Thirty-three adolescent baseball pitchers with a minimum of 2 years of pitching experience underwent 3-dimensional motion analysis using reflective markers aligned to bony landmarks. After a warm-up, pitchers threw either a fastball or curveball, randomly assigned, from a portable pitching mound until 3 appropriate trials were collected for each pitch technique. Kinematic and kinetic data for the upper extremities, lower extremities, thorax, and pelvis were collected and computed for both pitch types. Statistical analysis included both the paired sample t test and mixed model regression.

**Results:** There were lower moments on the shoulder and elbow when throwing a curveball versus when throwing a fastball. As expected, speed for the 2 pitches differed: fastball, 65.8 ± 4.8 mph; and curveball, 57.7 ± 6.2 mph ($P < .001$). Maximal glenohumeral internal rotation moment for the fastball was significantly higher than for the curveball (59.8 ± 16.5 N·m vs 53.9 ± 15.5 N·m; $P < .0001$). Similarly, the maximum varus elbow moment for the fastball was significantly higher than for the curveball (59.6 ± 16.3 N·m vs 54.1 ± 16.1 N·m; $P < .001$). The wrist flexor moment was greater in the fastball, 8.3 ± 3.6 N·m, than in the curveball, 7.8 ± 3.6 N·m ($P < .001$), but the wrist ulnar moment was greater in the curveball, 4.9 ± 2.0 N·m, than in the fastball, 3.2 ± 1.5 N·m ($P < .001$). Relatively minor motion differences were noted at the shoulder and elbow throughout the pitching motion, while significant differences were seen in forearm and wrist motion. The forearm remained more supinated at each point in the pitching cycle for the curveball but had less overall range of motion (62° ± 20°) than with the fastball (69° ± 17°) ($P < .001$), and the difference in the forearm pronation and supination moment between the pitches was not significant ($P = .104$ for pronation and $P = .447$ for supination). The wrist remained in greater extension during the fastball from foot contact through ball release but did not have significantly different total sagittal range of motion (53° ± 11°) when compared with the curveball (54° ± 15°) ($P = .91$).

**Conclusion:** In general, the moments on the shoulder and elbow were less when throwing a curveball than when throwing a fastball. In each comparison, the fastball demonstrated higher moments for each individual pitcher for both joints.

**Clinical Relevance:** The findings based on the kinematic and kinetic data in this study suggest that the rising incidence of shoulder and elbow injuries in pitchers may not be caused by the curveball mechanics. Further evaluation of adolescent and adult baseball pitchers is warranted to help determine and subsequently reduce the risk of injury.

**Keywords:** baseball pitching; adolescent sports; kinetics; kinematics; motion analysis

It is estimated that more than 6 million adolescents participate in organized baseball in the United States. During the course of their participation, their bodies and specifically their dominant arms are subject to significant forces during play. Shoulder and elbow injuries in particular are a common problem for pitchers of all ages and can limit or terminate participation in baseball and may ultimately affect activities of daily living as they grow older. If the specifics of the injury mechanisms that occur while

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throwing a baseball can be elucidated, the proper pitching techniques can be taught to limit use of potentially harmful techniques. Comprehensive 3-dimensional motion analysis is an ideal tool to study in detail the biomechanics of the pitching motion.

As opposed to a single traumatic event, most baseball arm injuries are thought to be due to the accumulation of microtrauma from repeated pitching experiences.[4,11,13,18] Studies have also suggested that an increased risk of shoulder and elbow pain in adolescent pitchers is associated with pitch types, pitch counts, and pitch mechanics.[8,14-16,19,20] Although these and other studies have implied that the throwing of a curveball places higher moments on the arm than throwing other pitches, to our knowledge, this has not been conclusively determined. The current recommendations suggesting that breaking pitches be avoided before 14 (curveball) and 16 (slider) are based on epidemiological data.[15,19]

Dun et al[5] in an analysis of the fastball, curveball, and the change-up techniques for pitchers 12.5 ± 1.7 years old showed that the fastball places higher loads on the adolescent pitcher's shoulder and elbow. This is in agreement with previous work from the same laboratory on more experienced pitchers.[7] In Dun's study, increased joint moments and forces were noted for the fastball compared with the curveball at key points in the pitch cycle. These findings are not consistent with previous research and with general understanding in coaching circles. More studies are needed across a spectrum of ages to determine the biomechanical differences between fastball and curveball pitching techniques to clarify this inconsistency.

USA Baseball has made recommendations regarding the types of pitches thrown (ie, no curveballs before the age of 14 years) during a youth baseball game.[1] These recommendations also include limits in the overall number of pitches that should be thrown in a game, a week, and in a season. This second set of recommendations is intuitively obvious. Little League Baseball has adopted a set of similar recommendations (2007) and added a period of rest between pitching outing based on the number of throws made (LittleLeagueBaseball.com).

Establishing the scientific data to support coaching practices will allow for more persuasive arguments that can be presented to young athletes and their coaches. In addition, the biomechanical data will provide a basis to avoid specific risky mechanics and assist in the teaching and coaching of proper pitching techniques leading to a reduction in pitching injuries.[1] Therefore, the purpose of this study was to further evaluate the difference in pitching biomechanics between the fastball and curveball pitching techniques for adolescent pitchers ranging in age from 14 to 18 years.

## MATERIALS AND METHODS

Thirty-three adolescent baseball pitchers between the ages of 14 and 18 years were recruited from local youth and high school baseball programs. Each pitcher had at least 2 years of pitching experience and reported that they had thrown a curveball competitively. No pitcher had a current complaint of arm pain. The Institutional Review Board at Connecticut Children's Medical Center approved the project. All subjects signed assent forms, and informed consent was obtained from their parents before involvement in the study.

A medical and pitching history was obtained. A physical examination was performed, and anthropomorphic measurements including height, weight, leg lengths, arm lengths, and joint range of motion were obtained from each subject. The subjects wore sneakers and shorts and were marked with a series of 38 reflective markers as previously described.[17] Subjects were given time to stretch and warm-up until they felt ready to throw normally. Pitchers were asked to throw a series of fastballs or curveballs, randomly chosen, into a netted target with a designated strike zone. An average of 16 pitches was thrown until 3 representative fastballs and 3 curveballs were obtained. The larger average pitch count versus valid pitch data was a result of both problems with incomplete data at the time of collection and the randomization of pitch types. Pitching motion data were captured via a 512 Vicon Motion Systems machine (Vicon Motion Systems, Lake Forest, California) using 12 synchronized cameras collecting data at 250 Hz. Initial data processing was performed on Workstation (Vicon Motion Systems), generating kinematics using established Euler equations. A fourth-order, zero-lag Butterworth digital filter was used to smooth the raw data with a 15-Hz cut-off frequency. Joint kinetics were then computed using customized Matlab codes using standard inverse dynamics.

Data were collected for previously described critical phases of the pitching cycle[8] (Figure 1) beginning with lead foot contact (FC), maximal glenohumeral external rotation (MER), ball release (BR), and finally maximal glenohumeral internal rotation (MIR). The entire cycle was time normalized to the pitch cycle with particular attention paid to FC, MER, BR, and MIR. Mean kinematic and kinetic plots through the pitch cycle were computed for chosen parameters. The individual data points for several parameters of interest were graphed to assess the contribution of within-subject and between-subject variations.

### Statistical Analysis

Means and standard deviations for kinematic and kinetic parameters were calculated after first averaging each subject's individual trials by pitch type. These were reported for ease of understanding. Because repeated measures were obtained from pitchers, it was not appropriate to use a traditional $t$ test to compare means. Two methods were employed to determine statistical significance of the difference between fastball and curveball pitches. A simple approach used the paired sample $t$ test to compare the mean difference by pitch type across all the players. A second, more sophisticated method used a random intercept mixed-effects regression model.[10,12] Like the paired $t$ test, the model also properly accounts for repeated measures from each pitcher but provides better precision by making use of all the data rather than averaging each subject's fastballs and curveballs. Occasionally fewer than 3 trials of each pitch type were available for analysis

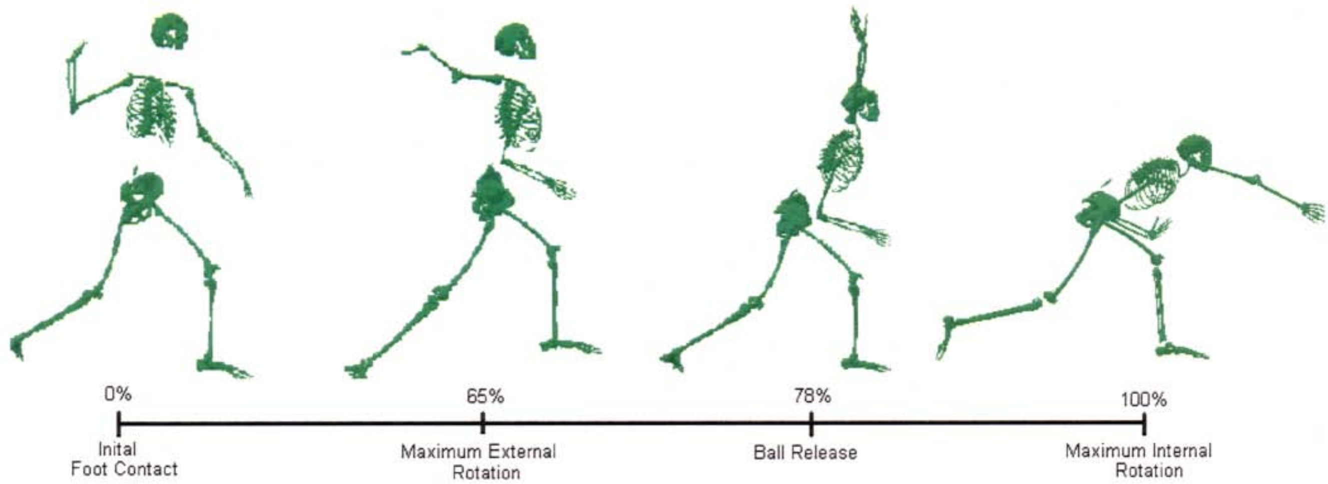


**Figure 1.** Pitching cycle as seen for a single pitch.

because of a marker not being captured by the cameras during the critical portion of the pitching motion. The regression method is able to accommodate for this modification and calculates proper standard errors to reflect the degree of precision available. The paired *t* test considers an average of 3 values to have the same precision as an average of 2 or even a single value. Additionally the regression method readily extends to a multivariate model to account for ball velocity and a subject's weight. Because results using the 2 methods were identical, the regression *P* values are reported as they are more appropriate.

A prestudy power analysis was performed using pilot data to determine the number of subjects needed to show a clinically meaningful difference (5 N·m) in elbow varus moment between the curveball and fastball. Data from 7 subjects showed a standard deviation of 5 N·m for the difference between the FB and CB on a single pitch. On the basis of these data, 33 subjects were needed to have 80% power to detect a 5-N·m difference with 95% confidence.

TABLE 1
Subject Information (N = 33)

| Characteristics and Data | |
|---|---|
| Age, y | 16.6 ± 1.5 |
| Weight, kg | 76.2 ± 12.5 |
| Height, cm | 179.4 ± 6.8 |
| Body mass index | 23.6 ± 3.1 |
| Fastballs pitched | 8 ± 2 |
| Fastball velocity, m/s | 29.5 ± 2.1 |
| Fastball velocity, mph | 65.8 ± 4.8 |
| Curveballs pitched | 8 ± 2 |
| Curveball velocity, m/s | 25.9 ± 2.8 |
| Curveball velocity, mph | 57.7 ± 6.2 |

## RESULTS

The study subjects had an average age of 16.6 years, with a mean body weight of 76.2 kg. The mean height was 179.4 cm, and body mass index (BMI) averaged 23.6 kg/m$^2$ (Table 1). The velocity of the fastball, 65.8 ± 4.8 mph, was consistently higher than the curveball, 57.7 ± 6.2 mph ($P < .001$).

### Kinematics

*Wrist.* As we have previously reported,[17] the wrist's greatest range of motion (ROM) occurred in the flexion-extension plane (Table 2 and Figure 1 of appendix, available in the online version of this article at http://ajs.sagepub.com/supplemental/). The overall arc of motion averaged 53° ± 11° for the fastball and 54° ± 15° for the curveball ($P = .91$). Wrist extension at FC for the fastball and curveball was 30° ± 17° and 24° ± 12° ($P < .001$), respectively, and the wrist remained extended significantly more for the fastball throughout the pitching cycle (PC) ($P < .001$). We also noted a greater radioulnar ROM for the wrist throwing a curveball (17° ± 7°) as compared with the fastball (14° ± 5°) ($P < .001$). The peak sagittal (flexion-extension) velocity of wrist motion occurred at 78% ± 8% of the PC for the fastball (1871 ± 431 deg/s) compared with 82% ± 3% for the curveball (1857 ± 569 deg/s). While minimal radial and ulnar deviation was seen in either pitch type (Table 2 and Figure 1 of appendix, available in the online version of this article at http://ajs.sagepub.com/supplemental/), ulnar wrist angular velocity was significantly different between pitches at the point of BR and had an actual peak near the end of the PC (after BR and near MIR) (Table 3 and Figures 5 and 8 of appendix, available in the online version of this article at http://ajs.sagepub.com/supplemental/). At the point of BR, a higher ulnar velocity was noted for the curveball (360 ± 217 deg/s vs 154 ± 261 deg/s) ($P < .001$). The ulnar velocity near the end of the PC remained somewhat constant for the curveball (393 ± 211 deg/s) and increased dramatically for the fastball (492 ± 266 deg/s) ($P = .55$) (Figures 5 and 8 of appendix,

TABLE 2
Wrist and Forearm Kinematics[a]

| | | Fastball, deg | Curveball, deg | P |
|---|---|---|---|---|
| Forearm rotation angle (+pronation/–supination) | FC | 10 ± 22 | –5 ± 22 | <.0001 |
| | MER | –3 ± 14 | –20 ± 12 | <.0001 |
| | BR | 6 ± 13 | –13 ± 11 | <.0001 |
| | MIR | 48 ± 25 | 29 ± 19 | <.0001 |
| | ROM | 69 ± 17 | 62 ± 20 | <.0001 |
| Mean forearm pronation | FC to BR | 7 ± 11 | –10 ± 15 | <.0001 |
| Wrist sagittal angle (+flexion/–extension) | FC | –30 ± 17 | –24 ± 12 | <.0001 |
| | MER | –42 ± 8 | –36 ± 9 | <.0001 |
| | BR | –27 ± 6 | –22 ± 7 | <.0001 |
| | MIR | –8 ± 13 | 3 ± 13 | <.0001 |
| | ROM | 53 ± 11 | 54 ± 15 | .91 |
| Wrist coronal angle (+ulnar/–radial) | FC | –7 ± 6 | –8 ± 6 | .832 |
| | MER | –2 ± 6 | –3 ± 6 | .136 |
| | BR | –0.4 ± 5 | 1 ± 5 | .0001 |
| | MIR | 4 ± 6 | 6 ± 5 | .017 |
| | ROM | 14 ± 5 | 17 ± 7 | <.0001 |

[a]FC, foot contact; MER, maximal glenohumeral external rotation; BR, ball release; MIR, maximal glenohumeral internal rotation; ROM, range of motion. N = 33 average of repeated trials for each subject. Fastball: 3 trials = 23, 2 trials = 6, 1 trial = 4. Curveball: 3 trials = 22, 2 trials = 9, 1 trial = 2.

TABLE 3
Maximum Glenohumeral (GH), Elbow, Forearm, and Wrist Angular Velocity and Timing (Angular Velocity, deg/s)[a]

| | Fastball | Curveball | P |
|---|---|---|---|
| GH internal rotation | 3619 ± 656 | 3409 ± 722 | .023 |
| GH internal rotation, %PC | 77 ± 8 | 81 ± 4 | .008 |
| Elbow flexion | 976 ± 347 | 890 ± 371 | .087 |
| Elbow flexion, %PC | 88 ± 7 | 84 ± 14 | .570 |
| Elbow extension | 1925 ± 354 | 1841 ± 291 | .091 |
| Elbow extension, %PC | 70 ± 8 | 74 ± 5 | .010 |
| Forearm pronation between BR and 100% | 2444 ± 522 | 2214 ± 390 | .053 |
| Forearm pronation, %PC | 85 ± 4 | 88 ± 4 | .005 |
| Wrist ulnar velocity at BR | 154 ± 261 | 360 ± 217 | <.0001 |
| Wrist ulnar velocity between 65% and 85% of PC | 272 ± 166 | 415 ± 220 | .0007 |
| Wrist ulnar velocity, %PC | 74 ± 6 | 75 ± 6 | .456 |
| Wrist ulnar velocity between 90% and 100% of PC | 492 ± 266 | 393 ± 211 | .054 |
| Wrist ulnar velocity, %PC | 94 ± 3 | 97 ± 3 | .001 |
| Wrist flexion | 1871 ± 431 | 1857 ± 569 | .841 |
| Wrist flexion, %PC | 78 ± 8 | 82 ± 3 | .004 |

[a]PC, pitch cycle; BR, ball release. Timing: percentage of pitch cycle. N = 33 average of repeated trials for each subject. Fastball: 3 trials = 23, 2 trials = 6, 1 trial = 4. Curveball: 3 trials = 22, 2 trials = 9, 1 trial = 2.

available in the online version of this article at http://ajs.sagepub.com/supplemental/).

*Forearm.* The ROM for forearm rotation (supination-pronation) was significantly different between the 2 types of pitches, averaging 69° ± 17° for the fastball and 62° ± 20° for the curveball ($P$ < .001). The forearm remained significantly more pronated at each point of the PC for the fastball as compared with the curveball (Table 2 and Figure 1 of appendix, available in the online version of this article at http://ajs.sagepub.com/supplemental/). The peak forearm pronation velocity occurred at 85% ± 4% and 88% ± 4% of the PC for the fastball (2444 ± 522 deg/s) and curveball (2214 ± 390 deg/s), respectively, both occurring after BR (Table 3 and Figures 5 and 9 of appendix, available in the online version of this article at http://ajs.sagepub.com/supplemental/).

*Elbow.* Elbow ROM differed between the 2 types of pitches with the fastball having an overall greater arc (83° ± 14° vs 81° ± 14°) ($P$ = .001) (Table 4). The peak elbow extension velocity was greater for the fastball (fastball peak velocity of 1925 ± 354 deg/s vs 1841 ± 291 deg/s for the curveball) ($P$ = .09) and occurred earlier in the PC than the curveball (70% ± 8% vs 74% ± 5%) (Table 3 and Figures 1, 5, and 7 of appendix, available in the online version of this article at http://ajs.sagepub.com/supplemental/).

*Shoulder.* The overall arc of motion for the glenohumeral joint was slightly greater for the fastball (fastball, 124° ± 12° vs curveball, 117° ± 17°) ($P$ < .001) (Table 4 and Figure 1 of appendix, available in the online version of this article at http://ajs.sagepub.com/supplemental/). The MER of the glenohumeral (GH) joint was not different with the fastball reaching a peak of 135° ± 20° and the curveball reaching a peak of 135° ± 17° ($P$ = .36). The peak velocity of glenohumeral internal rotation velocity was slightly higher for the fastball (3619 ± 656 deg/s) versus the curveball (3409 ± 722 deg/s) ($P$ = .023) (Table 3 and Figures 5 and 6 of appendix, available in the online version of this article at http://ajs.sagepub.com/supplemental/).

## Kinetics

*Wrist.* As we previously reported,[17] peak moments about the wrist reported in younger pitchers are substantially lower than those about the elbow and shoulder. Peak wrist

TABLE 4
Glenohumeral (GH) and Elbow Kinematics[a]

| | | Fastball, deg | Curveball, deg | *P* |
|---|---|---|---|---|
| GH rotation angle (+internal/–external) | FC | –52 ± 31 | –56 ± 30 | .019 |
| | MER | –135 ± 20 | –135 ± 17 | .361 |
| | BR | –110 ± 23 | –111 ± 17 | .071 |
| | MIR | –13 ± 18 | –19 ± 20 | <.0001 |
| | ROM | 124 ± 12 | 117 ± 17 | <.0001 |
| GH coronal ROM | FC to MIR | 22 ± 10 | 20 ± 9 | .009 |
| GH sagittal ROM | FC to MIR | 35 ± 8 | 32 ± 8 | <.0001 |
| Elbow sagittal angle (+flexion/–extension) | FC | 100 ± 15 | 100 ± 14 | .978 |
| | MER | 73 ± 18 | 75 ± 19 | .579 |
| | BR | 40 ± 16 | 44 ± 18 | .077 |
| | ROM | 83 ± 14 | 81 ± 14 | .001 |

[a]FC, foot contact; MER, maximal glenohumeral external rotation; BR, ball release; MIR, maximal glenohumeral internal rotation; ROM, range of motion. N = 33 average of repeated trials for each subject. Fastball: 3 trials = 23, 2 trials = 6, 1 trial = 4. Curveball: 3 trials = 22, 2 trials = 9, 1 trial = 2.

flexion moment was slightly higher for the fastball than the curveball (8.3 ± 3.6 N·m vs 7.8 ± 3.6 N·m) ($P < .001$), whereas the ulnar moment was higher for the curveball, 4.9 ± 2.0 N·m, versus the fastball, 3.2 ± 1.5 N·m ($P < .001$) (Table 5), and both occur before MER (Figure 4 of appendix, available in the online version of this article at http://ajs.sagepub.com/supplemental/).

*Forearm.* The absolute values of the forearm moments were, similar to the wrist, meaningfully lower than those for the elbow and shoulder and comparable between the 2 pitch types. Forearm pronation moments were 1.7 ± 1.2 N·m for the fastball and 1.9 ± 0.9 N·m for the curveball ($P = .10$) (Table 5).

*Elbow.* Elbow moments were significantly different between the fastball and curveball. The fastball peak varus moment was 59.6 ± 16.3 N·m compared with the curveball varus moment of 54.1 ± 16.1 N·m ($P < .001$) (Table 6 and Figure 3 of appendix, available in the online version of this article at http://ajs.sagepub.com/supplemental/).

*Shoulder.* Kinetic calculations about the shoulder closely paralleled those of the elbow. The GH maximal internal rotation moment occurred just before BR for both the fastball and the curveball and was 59.8 ± 16.5 N·m versus 53.9 ± 15.5 N·m, respectively ($P < .001$). The GH flexion moment was 56.8 ± 18.3 N·m and 52.0 ± 17.4 N·m ($P < .001$) for the fastball and the curveball, respectively (Table 6 and Figure 2 of appendix, available in the online version of this article at http://ajs.sagepub.com/supplemental/).

In this set of pitchers, as well as previous studies in our laboratory, we have noticed a large variation in pitching styles and mechanics between pitchers. This makes a comparison of the group means difficult. We have therefore chosen to evaluate each pitcher individually comparing his curveball kinematics and kinetics directly to his fastball values. In doing this, we have been able to identify valid and reproducible differences between the pitch types. Further, we have discovered that while there is a large difference between pitchers, each of our studied pitchers demonstrated consistent kinematics and kinetics in all parameters measured and evaluated.

TABLE 5
Wrist and Forearm Kinetics (Maximum Moments, N·m)[a]

| | Fastball | Curveball | *P* |
|---|---|---|---|
| Forearm pronation | 1.7 ± 1.2 | 1.9 ± 0.9 | .104 |
| Forearm supination | 2.3 ± 1.6 | 2.4 ± 1.1 | .447 |
| Wrist flexion | 8.3 ± 3.6 | 7.8 ± 3.6 | .0008 |
| Wrist radial | 0.7 ± 1.9 | 0.2 ± 1.6 | .062 |
| Wrist ulnar | 3.2 ± 1.5 | 4.9 ± 2.0 | <.0001 |

[a]N = 33 average of repeated trials for each subject. Fastball: 3 trials = 23, 2 trials = 6, 1 trial = 4. Curveball: 3 trials = 22, 2 trials = 9, 1 trial = 2.

TABLE 6
Glenohumeral (GH) and Elbow Kinetics (Maximum Moments, N·m)[a]

| | Fastball | Curveball | *P* |
|---|---|---|---|
| GH internal moment | 59.8 ± 16.5 | 53.9 ± 15.5 | <.0001 |
| GH flexion moment | 56.8 ± 18.3 | 52.0 ± 17.4 | <.0001 |
| Elbow varus moment | 59.6 ± 16.3 | 54.1 ± 16.1 | <.0001 |

[a]N = 33 average of repeated trials for each subject. Fastball: 3 trials = 23, 2 trials = 6, 1 trial = 4. Curveball: 3 trials = 22, 2 trials = 9, 1 trial = 2.

## DISCUSSION

Fleisig et al[9] recently reported that there does not appear to be any significant differences in the moment placed on the medial elbow or anterior structures of the shoulder when throwing a curveball versus a fastball in elite level pitchers. Dun et al[5] also found reduced loads in adolescent pitchers when throwing a change-up or a curveball when compared with a fastball. We similarly found statistically lower moments throwing the curveball than the fastball in adolescent pitchers (aged 14-18 years). These findings are contrary to the long-held belief that throwing a curveball places the arm at a higher risk of injury than throwing a fastball. However, these findings are not surprising when comparing the motion of the pitches and given the difference in ball velocity generated between the 2 pitch types. We found that the magnitude of the moments at the glenohumeral ($P = .0001$) and elbow ($P = .0001$) joints is directly correlated to ball velocity. Therefore, one would expect lower joint moments with the slower curveball and higher moments with the fastball. This is mathematically consistent when one considers that the moments are calculated with inverse dynamics, which are dependent on ball and arm segment velocities.

Previous work in our laboratory has noted high variability between pitchers throwing similar pitch types. This variability is expected in younger, less experienced pitchers. We previously noted large variability in fastball pitching technique in 10- to 14-year-old pitchers.[17] The current group of pitchers was slightly older and more experienced. Given our interest in looking at biomechanical forces, especially of the throwing arm, the inclusion of these more experienced pitchers was intentional. The variability across these older pitchers was significantly less and has suggested to us the possibility that the less experienced pitchers with potentially incorrect technique, throwing a high number of pitches in a concentrated time frame, may be a risk factor for injury. One would theorize that if this were the case, however, that fatigue, which would intuitively cause an increase in biomechanical variability, would also lead to an increased risk of injury. However, our laboratory and others[6] have been unable to induce a significant change in the biomechanics of pitching simply by fatiguing the pitcher.

Another concern regarding the risk associated with throwing a curveball involves forearm pronation and supination during the pitch cycle. Some have suggested that rapid supination exposes the elbow to high valgus moments and may lead to increased injury rates. Using our model, we were able to look at both forearm rotation (supination and pronation) and wrist motion during the pitch cycle. As mentioned, the differences between the fastball and curveball pitches seen at the forearm and the wrist were more positional than in arc of motion. The forearm remained more supinated and the wrist more flexed during the cocking and acceleration phases (phases of the PC associated with higher joint moments) of each curveball as compared with the fastball. There were minimal differences between the fastball and curveball in the sagittal plane (flexion/extension), although interestingly peak flexion was higher for the curveball than for the fastball. We did not find a significant difference between the pitch types in peak wrist extension as previously described.[2] The forearm started more supinated and remained more supinated during the throwing of a curveball as compared to the fastball, although the positional changes (arc of motion) were remarkably similar and the graphs appear to mirror one another (Figure 1 of appendix, available in the online version of this article at http://ajs.sagepub.com/supplemental/). This is again different than found previously where the forearm position, although more supinated for the curveball throughout most of the PC, did intersect shortly after BR.[2] The forearm rotation moments were not statistically significant between the pitch types, and the differences noted were minimal and in our opinion of no clinical significance. The wrist ulnar and flexion moments were statistically significant between the pitches with the curveball showing a higher moment. Again, however, we do not believe that the absolute values of these moments are clinically significant, although biomechanical data for risky wrist motion forces have not been established to our knowledge.

Reviewing the pitching motion data, several positional differences between the pitch types were noted. The forearm was more supinated when throwing a curveball at each analyzed point in the PC as compared with the fastball, while the wrist was more extended for the fastball than the curveball, and these differences were statistically significant. These differences indicate that our adolescent pitchers were indeed throwing different pitches when asked to and when they reported doing so. According to pitching coaches, a correctly thrown curveball creates spin using the wrist and not the forearm. A "12-to-6" curveball motion takes a radially deviated wrist that rapidly moves into ulnar deviation around the time of ball release, as noted in the wrist data collected in this study. Biomechanically, in order to position the wrist to have this radial to ulnar motion, the forearm needs to be held in a roughly neutral position (minimal supination or pronation). Again, a supinated position at each point of the PC for the curveball as compared with the fastball was noted in the forearm transverse plane motion data. This would suggest that the pitchers in this study were pitching using a technique considered by coaches as a good curveball-pitching technique. Interestingly, we found similar wrist flexion velocities for both pitch types, which does not fit the long-held belief that pitchers generate some velocity on their fastball with rapid wrist flexion.

Our findings do have some limitations. The study was performed within a laboratory without a catcher or a batter in the box. Both situations, as well as other distractions that might exist in a live game, could result in alterations in the pitching motion that might create abnormal mechanics and thus increased joint loads. We also realize that the age range of our pitchers covers a wide range of maturation. We do report here on a greater number of adolescent pitchers than elsewhere in the literature; however, the differences between stages of physical maturity were not analyzed and are a subject of ongoing research.

The curveball mechanics as defined by the kinematics of this article suggest that throwing a curveball per se may not cause the rising incidence of injuries for young (14-18 year old) pitchers. We cannot suggest, however, that curveballs or other breaking-type pitches thrown by pitchers who use different methods such as the palm curve or pronation curve not evaluated in this study do not result in a higher risk of injury. Furthermore, while we have demonstrated that higher moments exist for the fastball than for the curveball in the pitchers studied, this may not reflect mechanics and resultant moments in other pitchers with either superior or inferior mechanics.

The number of pitches thrown coupled with the lack of appropriate rest periods appear to be a greater contributor to the increasing incidence in pitcher arm injuries.[3,4] The ultimate description of the cause of pitcher injuries is an area of ongoing research. Our future endeavors will focus on kinematic and kinetic analyses of additional pitch types.

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