Relationship between throwing mechanics and elbow valgus in professional baseball pitchers

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Valgus elbow stress leads to medial tension and lateral compression injuries in baseball pitchers of all ages. This study was undertaken to investigate the relationship between elbow stress in professional baseball pitchers and the kinematic parameters of pitching mechanics. This was done in an attempt to understand valgus extension overload better and in an effort to improve preventive and rehabilitative protocols. High-speed video data were collected on 40 professional pitchers in game situations during the 1998 and 1999 Cactus League season in Arizona, as part of Major League Baseball Spring Training. A multiple linear regression analysis was used to relate elbow valgus to kinematic parameters of pitching mechanics. The resulting analysis produced an adjusted multiple R^2 value of 0.974, indicating that nearly 100% of the variance in valgus stress on the elbow was explained by the parameters in the regression equation. This ability to explain over 97% of the variance in valgus stress is significant. The parameters of pitching mechanics related to elbow valgus may be assessed and optimized, if necessary, in order to decrease the magnitude of elbow stress in pitching. (J Shoulder Elbow Surg 2002;11:151-155.)

Elbow injuries are frequently observed in baseball pitchers of all levels.[6,10,12] Elbow pain is the most common complaint among pre-adolescent and adolescent baseball pitchers,[6] and elbow injuries continue to be prevalent in college and professional pitchers. According to Tullos and King,[10] 50% of professional baseball pitchers experience elbow or shoulder pain sufficient enough to keep them from throwing at some time in their careers.

Because of the high speeds of movement and excessive ranges of motion in pitching, the elbow joint is particularly susceptible to injury. During the delivery phase of pitching, maximum external rotation (MER) at the shoulder joint ranges from 150° to 180°.[2,5,13] Elbow extension speeds as high as 3000°/s have been observed.[2,3,13] The forces and torques producing these movements at the shoulder and elbow place tremendous tension on the soft tissues of the medial side of the elbow and tend to compress the lateral side. This type of loading, termed valgus extension overload,[4,12] is thought to be the major pathologic mechanism of the elbow in throwing. Werner et al[11] reported a mean peak valgus torque of 120 Nm for a professional population of pitchers.

The anterior bundle of the ulnar collateral ligament has been described as the primary stabilizer of the elbow when it is subjected to valgus stress.[7,9] However, according to preliminary cadaver studies, the ulnar collateral ligament fails under less stress than that which is thought to occur during pitching.[11] Werner et al[11] described the role of the triceps, wrist flexor-pronator mass, and anconeus during peak valgus stress as dynamic stabilizers to assist the ulnar collateral in preventing valgus extension overload. The purpose of this study was to investigate the relationship between valgus stress on the elbow and the kinematic parameters of pitching mechanics during the throwing motion in professional baseball pitchers.

METHODS

Forty professional baseball pitchers served as subjects in the study. Mean age was 28 ± 5 years (range, 20-37 years), with a mean height and mass of 188 ± 5 cm and 90 ± 10 kg, respectively. Thirty-two were right-handed, and 8 left-hand dominant. Data were collected in game situations during the 1998 Cactus League season in Arizona as part of Major League Baseball Spring Training. The method of data collection involved the use of three 120-Hz cameras (Peak Performance Technologies, Englewood, Colo). Two cameras were placed in the right and left field bleachers and were used as side views depending on whether the pitcher was right- or left-handed. The third camera was used

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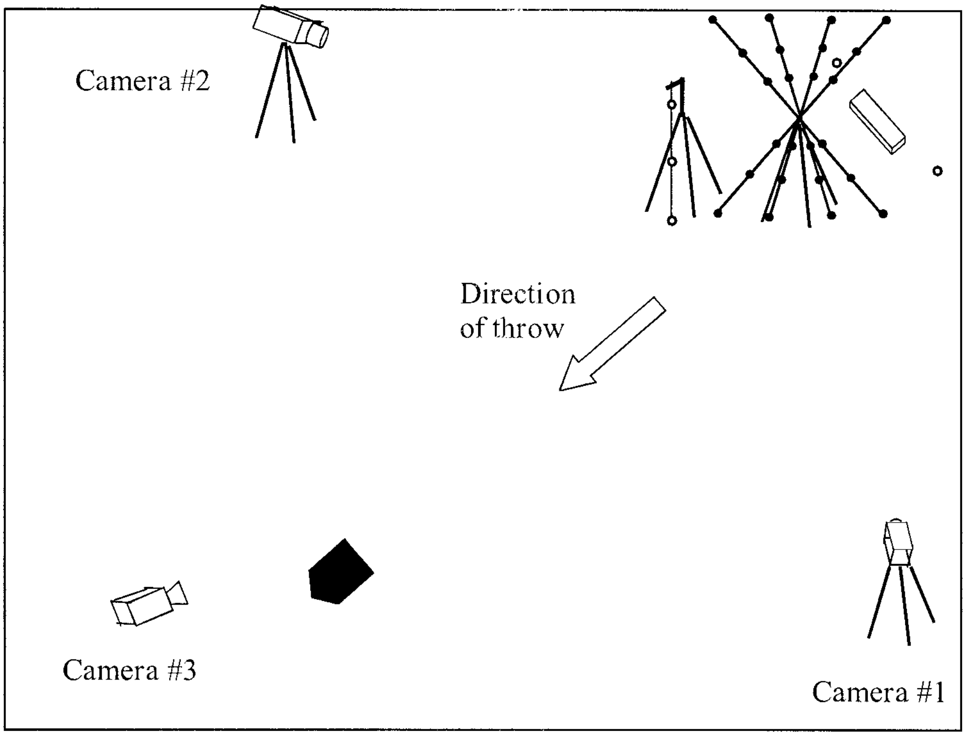

Figure 1 Schematic of data collection setup. Reprinted with permission from Murray et al.[8]

for all throwers and was placed above and behind home plate in the press box. Figure 1 depicts the setup for data collection.

In order to calibrate the pitching area, a 24-point calibration frame (Peak Performance Technologies) was videotaped simultaneously by all 3 cameras. Horizontal and vertical reference markers were also placed on the pitching mound in order to create a pitching relevant reference frame (Figure 1). The forty pitchers were then videotaped from the front and appropriate throwing sides. At least 2 innings of high-speed video data were collected for each athlete as he threw the regulation distance of 60 ft, 6 in (18.4 m). The mass of the 9 in (23 cm) circumference ball was 5 oz (0.14 kg). All pitches were charted from above and behind home plate during data collection. In an effort to reduce the cost (ie, extensive time spent on manual digitization) associated with an aggregate analysis, one fastball thrown for a strike was chosen for each pitcher. When quality data were collected from both camera views for multiple fastballs thrown for strikes in the same inning, the pitch with highest ball speed was analyzed.

A Peak Performance Motus system was used to digitize the locations of the ball and twenty body landmarks for each subject manually.[8] All of the points, with the exception of the great toe, heel, and crown of the head, were digitized as approximations of joint centers in each successive frame. The time interval from 50 ms prior to the instant the ball left the glove until 500 ms after ball release was studied. The Direct Linear Transformation method was used to obtain 3-dimensional coordinate data for the ball and each body landmark. Data from the 2 cameras were synchronized on the instant of ball release. Coordinate data were conditioned with a Butterworth fourth order, zero lag digital filter (cutoff = 10 Hz). All coordinate data were expressed in terms of the mound relevant reference frame.

The duration of the windup phase of the pitching sequence (from the initiation of movement until the ball leaves the glove) varies between pitchers. Temporal phases were defined from stride foot contact (SFC) to the instant of maximum shoulder external rotation (MER), the cocking phase; from MER to the instant of ball release (REL), the acceleration phase; and from REL until 500 ms after REL, the follow-through phase. Linear velocity and acceleration for each landmark was calculated with Peak Motus utilities. Knee and elbow angles were also calculated with Motus utilities, and shoulder angles were calculated via methods described by Feltner.[1] Elbow angle convention is depicted in Figure 2. All angular velocities were calculated as the first derivative of the time-dependent angular displacements.

The forces and torques at the shoulder and elbow joints of the throwing arm were calculated according to methods described by Feltner and Dapena.[2] Figure 3 depicts the anatomically relevant elbow and shoulder joint reference frames used to describe the kinetic parameters. In order to normalize data between subjects, forces were expressed as percent body weight (%WGT) and torques as percent body weight and height (%WGT*HGT).

A standard statistical software package (SYSTAT, Chicago, Ill) was used to reduce the kinematic and kinetic data further. Descriptive statistics were obtained for the 40 pitchers, and multiple linear regression analysis was used to relate elbow valgus to kinematic parameters of pitching mechanics. A correlation analysis was carried out for all variables and all possible noncorrelated combinations of

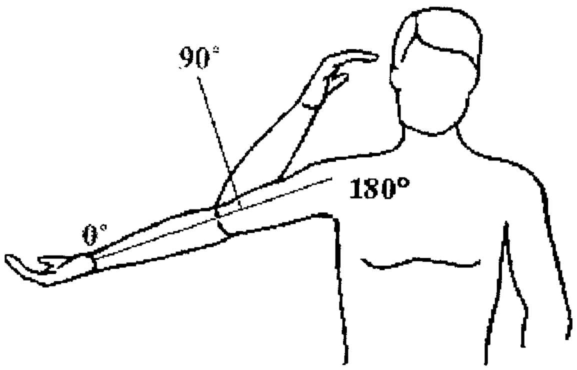

Figure 2 Elbow angle convention.

the kinematic and kinetic parameters were assessed in order to reach the optimal set of parameters. A multiple regression analysis was carried out to assess the combined effects of various kinematic and kinetic parameters on elbow valgus. The regression analysis was carried out on the optimal combination of noncorrelated parameters, which included a constant and 37 kinematic and kinetic variables. Table I lists these variables.

RESULTS

The mean ball velocity at REL for the 40 fastballs was 40 ± 1 m/s (89 ± 3 mph). Valgus stress at the elbow joint was thought to be indicative of injury potential and chosen as the dependent variable because this load has been associated with subsequent medial tension and lateral compressive pathologies.[11,12] Table II depicts ANOVA for the final model. The final regression equation is displayed in the Appendix. Residual plots indicated that none of the traditional regression assumptions was violated. The adjusted multiple R^2 value was 0.974, indicating that over 97% of the variance in the valgus stress on the elbow was explained by the regression equation. The standard error of estimate was 2.71. All 4 of the regression variables were statistically significant ($P < .05$) and are depicted in Table III.

Elbow valgus was most affected by the shoulder abduction angle at SFC, maximum horizontal adduction angular velocity, elbow angle at peak valgus stress and peak shoulder external rotation torque. Mean shoulder abduction at SFC for the 40 pitchers was 109° ± 33°. Mean peak shoulder horizontal adduction angular velocity was 933° ± 320°/s. Elbow angle at peak valgus torque averaged 98° ± 21° and maximum external rotation torque averaged 111 ± 17 Nm for the 40 athletes. The magnitude of elbow valgus stress was increased by greater degrees of shoulder abduction at SFC, increased horizontal adduction angular velocity, increased (ie, more flexed) elbow angle at peak valgus torque and decreased external rotation torque.

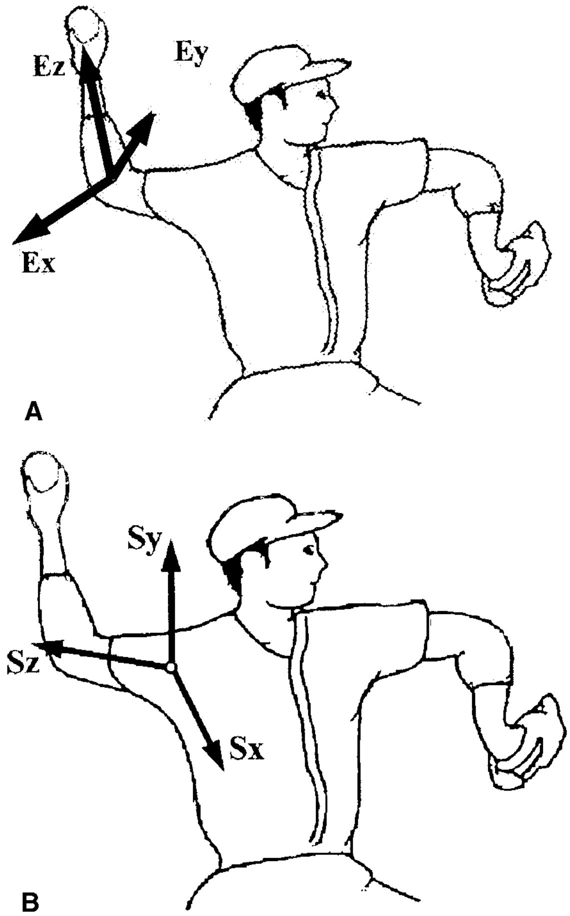

Figure 3 Anatomically relevant reference frames at the elbow **(A)** [Ex represents the shear component of force in the medial(+)/lateral(−) direction and the axis of the extension(+)/flexion(−) torque; Ey represents the shear component of force in the superior(+)/inferior(−) direction and the axis of the varus(+)/valgus(−) torque; and Ez represents elbow distraction(+)/compression(−)] and shoulder **(B)** [Sx represents the shear component of force in the anterior(+)/posterior(−) direction and the axis of the adduction(+)/abduction(−) torque; Sy represents the shear component of force in the superior(+)/inferior(−) direction and the axis of the horizontal adduction(+)/horizontal abduction(−) torque; and Sz represents shoulder distraction(+)/compression(−) force and the axis of the external(+)/internal(−) rotation torque].

DISCUSSION

It is well accepted that the baseball pitching motion places tremendous stress on the elbow joint. The term valgus extension overload is commonly used to describe this stress. Several biomechanical studies[1-3,5,11,13] have documented valgus loads in excess of 115 Nm over the medial elbow near the instant of maximum external rotation. Clinicians dealing with overhead throwers are particularly cognizant of the susceptibility of these athletes to medial tension/lateral compression injuries to the elbow joint. The ability to explain 97% of the vari-

Table I Thirty-seven variables entered into elbow valgus multpile regression analysis

Variable (units)
Ball velocity (m/s)
Time between SFC and MER (s)
Stride length (%HGT)
Shoulder abduction angle at SFC (°)
Shoulder horizontal adduction angle at SFC (°)
Shoulder external rotation at SFC (°)
Knee angle at SFC (°)
Elbow angle at SFC (°)
Max hip angular velocity (°/s)
Max shoulder angular velocity (°/s)
Max shoulder horizontal adduction angular velocity (°/s)
Elbow angle at initial elbow extension (°)
Max horizontal adduction angle (°)
Max external rotation of the shoulder (°)
Max elbow extension angular velocity (°/s)
Max shoulder internal rotation angular velocity (°/s)
Average shoulder abduction angle from MER to REL (°)
Knee angle at REL (°)
Trunk tilt angle above horizontal at REL (°)
Elbow angle at REL (°)
Max elbow angle (°)
Average shoulder linear velocity for 30 ms after REL (m/s)
Average shoulder angular velocity for 30 ms after REL (°/s)
Elbow valgus loading rate (Nm/s)
Elbow angle at instant of peak valgus torque (°)
Shoulder adduction torque at MER (%WGT*HGT)
Shoulder horizontal adduction torque at MER (%WGT*HGT)
Shoulder external rotation torque at MER (%WGT*HGT)
Shoulder distraction force at REL (%WGT)
Shoulder adduction torque at REL (%WGT*HGT)
Shoulder horizontal abduction torque at REL (%WGT*HGT)
Shoulder external rotation torque at REL (%WGT*HGT)
Max elbow extension torque (%WGT*HGT)
Max shoulder distraction force (%WGT)
Max shoulder abduction torque (%WGT*HGT)
Max shoulder horizontal abduction torque (%WGT*HGT)
Max shoulder external rotation torque (%WGT*HGT)

Max, Maximum.

Table II ANOVA summary for elbow valgus multiple regression analysis

Source	Sum of squares	*df*	Mean square	F statistic
Regression	9912.81	4	2478.20	324.14*
Residual	267.59	35	7.65	

*Significant at $\alpha < .01$.

ance in valgus stress at the elbow joint in baseball pitching is significant to the clinical community.

Preliminary study also suggests that the ulnar collateral ligament cannot resist the excessive demands placed on it during baseball pitching and that the neuromuscular system offers support as a dynamic stabilizer.[11] Thus, valgus extension overload is a complex and career-threatening problem in throwers, and one that remains a problem for clinicians. The results of this study provide insight into the effects of pitching mechanics on valgus stress at the elbow joint. With careful consideration of the data, improved preventive and rehabilitative protocols may be produced.

Table III Significant variables in elbow valgus multiple regression analysis

Variable	Coefficient	Standard coefficient	*P* value
ABD@SFC	.035	.071	.017
MXHORADDW	.004	.079	.008
ELBPVT	–.048	–.062	.039
MXERT	–.962	–.986	.000

ABD@SFC, Shoulder abduction angle at instant of stride foot contact; *MXHORADDW,* peak shoulder horizontal adduction angular velocity; *ELBPVT,* elbow angle at instant of peak valgus torque; *MXERT,* maximum shoulder external rotation torque.

Four parameters were identified in this study that were responsible for 97% of the variance in elbow valgus stress. These were (1) shoulder abduction angle at stride foot contact, (2) peak shoulder horizontal adduction angular velocity, (3) elbow angle at the instant of peak valgus stress, and (4) peak shoulder external rotation torque. Although cause and effect relationships cannot be distinguished via regression analysis, the results indicate that a prediction of elbow valgus can be made based on 4 parameters of pitching mechanics. The associations between elbow valgus and the independent variables in the regression equation provide insight into avenues for reducing the stress that occurs at the elbow joint in pitching.

Throwers with more limited ranges of shoulder abduction at the instant of stride foot contact (109° ± 33°) appear to have lesser degrees of valgus stress at the elbow. The mean peak shoulder horizontal adduction angular velocity was 933° ± 320°/s, and pitchers who demonstrated lesser degrees of this angular velocity of shoulder horizontal adduction tended to limit this harmful elbow stress. A more flexed elbow at the instant of peak valgus torque appeared to reduce the extent of elbow valgus stress. Greater magnitudes of peak shoulder external rotation torque were also associated with a reduction of elbow valgus load. These guidelines provide a scientific basis for clinicians, athletes, and coaches to begin establishing methods to reduce valgus stress at the elbow joint. Subsequent attempts to assess, modify, and ultimately optimize this combination of parameters related to elbow valgus torque may provide the key to the reduction of injury prevalence in baseball pitching.

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APPENDIX

The following equation emerged from the multiple regression analysis:

$$\begin{aligned} VALGUS = {} & -5.221 + .035(ABD@SFC) \\ & + .004(MXHORADDW) \\ & - .048(ELBPVT) - .962(MXERT) \end{aligned}$$

in which VALGUS is the peak valgus torque at the elbow joint, ABD@SFC is the shoulder abduction angle at the instant of stride foot contact, MXHORADDW is the peak shoulder horizontal adduction angular velocity, ELBPVT is the elbow angle at the instant of peak valgus torque, and MXERT is the maximum shoulder external rotation torque.