INFLUENCE OF LATERAL TRUNK TILT ON THROWING ARM KINETICS DURING BASEBALL PITCHING

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The purpose of this study was to investigate the relationship between lateral trunk tilt angle and several injury-related kinetic parameters during pitching. Based on kinematic data of 12 overhand and three-quarter-hand pitchers, several pitching motions with different lateral trunk tilt angles from the original were simulated. Joint kinetics among the simulated motions was compared. As a result, elbow medial force and elbow varus torque were generally increased as the lateral trunk tilt increased, that is the greater contra-lateral side-bending to the throwing arm side. On the other hand, the shoulder shear force was decreased as the lateral trunk tilt increased. Data from the study demonstrated that the shoulder proximal force was irrelevant to the trunk tilt angle.

KEY WORDS: elbow kinetics, shoulder kinetics, simulation, direct kinematics, inverse dynamics

INTRODUCTION: In baseball pitching, it has been established that sidearm delivery tends to cause injury to a pitcher's throwing arm. Albright, Jokl, Shaw, and Albright (1978) investigated the relationship between pitching style and symptom of throwing injuries. They found that the pitchers employing a sidearm pitching style had a higher incidence of more severe symptoms in the elbow joint, than those who were overhand and three-quarter-hand pitchers. However, the reason for this has not been elucidated..

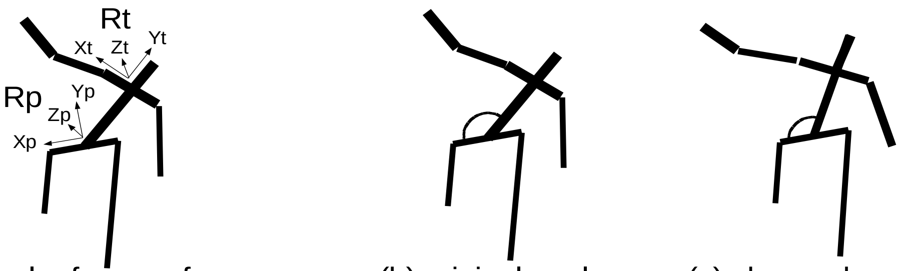
Fleisig et al. reported several kinetic variables that had implications for throwing injuries in their series of baseball pitching studies (1994, 1995a, 1995b). In their studies, it was suggested that elbow medial force and elbow varus torque were the most crucial variables for elbow injuries. In the pilot study for this research that investigated two professional sidearm pitchers, there appeared to be a tendency for them to have greater medial force, when compared with the overhand and three-quarter-hand pitchers.

There were several kinematic features of the sidearm pitchers that were investigated. These included the more erect trunk (the less lateral trunk tilt) and a greater shoulder horizontal adduction angle. For the other angular variables and any variables concerning angular velocity for throwing arm, significant differences were not found. The greater elbow force may be due to the less lateral trunk tilt and/or the greater shoulder horizontal adduction angle. Fleisig (1994) has already investigated the relationship between elbow medial force and shoulder horizontal adduction, and found a significant correlation between increased horizontal adduction and increased maximum elbow medial force, by investigating 72 college and professional overhand and three-quarter-hand pitchers. However, to date, there has been no study investigating relationship between the lateral trunk tilt and the throwing arm kinetics during pitching, including elbow medial force and elbow varus torque. Therefore, the purpose of this study was to investigate the relationship between the lateral trunk tilt and the kinetics during pitching.

METHODS: Data collection. Twelve overhand and three-quarter-hand professional baseball pitchers (mean height 1.84 ± 0.05 m, mean mass 81.3 ± 7.1 kg; mean age 20.9 ± 3.0 years) served as participants. The pitchers were videotaped by two high-speed cameras (HSV-400, NAC, Tokyo, Japan) at 200 Hz during pitching. Ball speed was recorded with a radar gun (PM-4A, Decatur Electronics, Inc., Decatur, IL). After the videotaping, the data set for the pitch with the fastest ball that struck the strike zone for each subject was selected for analysis. Video images were superimposed on the display of a personal computer. The third knuckle of the throwing arm, throwing wrist, throwing elbow, both shoulders, both hips, and the ball were manually digitized. In this study, data were analyzed from 40 frames (0.2 s) before the instant of ball release to 10 frames (0.05 s) after the instant of ball release. This duration corresponded to the duration from approximately 0.05 s before the lead foot contact to almost same instant of shoulder maximum internal rotation. The three-dimensional location of each point was calculated using DLT method and the data were smoothed using a fourth-order zero-lag Butterworth filter. The resultant cut-off frequency was decided for each direction in the global reference frame for each point, by using the residual analysis method (Winter, 1990). The range of the cut-off frequency was 6.2 Hz (left hip) - 13.6 Hz (right wrist). Four wires with four calibration markers were suspended vertically and were positioned so that the markers formed a matrix approximately 2.0 m X 2.0 m X 1.5 m in size. The root mean square error in calculation of the calibration markers was 0.3 cm.

Simulated motion and kinematics. Local reference frames were calculated at the pelvis (Rp) and the upper torso (Rt). The trunk vector was a unit vector from the mid-hip to the mid-shoulder. Xp was a unit vector from the mid-hip to the right hip, Zp was the cross-product of Xp and the trunk vector. Yp was the cross-product of Zp and Xp. Xt was a unit vector from the mid-shoulder to the right shoulder, Zt was the cross-product of Xt and the trunk vector, and Yt was the cross-product of Zt and Xt. The angle of lateral trunk tilt was defined as the angle between the trunk vector and Xp in the frontal (XtYt) plane (Figure 1). To change the lateral trunk tilt angle, Rt reference frame was rotated to some target angles (every 10º from 80º to 130º) around Zt axis.

Shoulder abduction angle, shoulder horizontal adduction, shoulder external rotation angle, and elbow flexion angle for the throwing arm were calculated using basically the same methods as the previous study (Feltner and Dapena, 1986). These shoulder and elbow joint angles in the original motion remained intact, and were used in the simulated motions as well as the changed Rt reference frame and the original segments' lengths.



(a) local reference frames (b) original angle (c) changed angle

Figure 1 - a) the local reference frame at the pelvis (Rp) and at the upper torso (Rt); b) the original lateral trunk tilt angle, and c) the changed lateral trunk tilt angle.

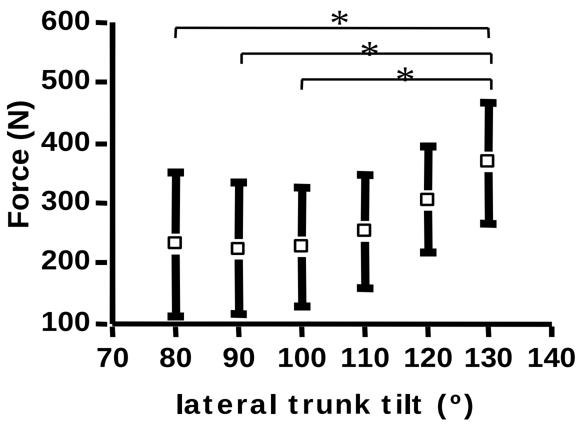
Joint kinetics. Resultant forces and torques on the throwing shoulder and the throwing elbow were also calculated using the same method previously reported, which used inverse dynamics of Newton equations (Feltner & Dapena, 1986; Fleisig et al., 1995a). The mass of a baseball was set equal to 0.145 kg and moment of inertia of ball was assumed to be negligible. Due to limitations in computer resolution of video image, mass of the ball and mass of the hand were assumed to be at the wrist. For the inertia properties of the body segments, Ae's regression model (Ae, Tang, & Yokoi, 1992) applying Jensen's method (1978) to Japanese athletes was used. The proximal resultant joint force and torque exerted on each link was calculated using the previously reported method (Feltner & Dapena, 1986; Fleisig et al., 1995a), beginning with the ball. The resultant torques of elbow and shoulder calculated in the global reference coordinates, were then transformed into forearm reference frame, and upper torso reference frame, respectively (Fleisig et al., 1995a). Although the shoulder force can be divided into three orthogonal components (anterior force, superior force, and proximal force), for the purpose of this study, it was divided into two components: shear force (resultant force of anterior force and superior force) and proximal force.

Data reduction and statistics. Selecting from data on the throwing arm kinetics, the study focused on the elbow medial force, the elbow varus torque, the shoulder shear force, and the shoulder proximal force, using only their maximum values. ANOVA were used on these kinetic parameters to assess the significant differences among the various simulated motions. Only p values < .01 were considered significant. Post hoc comparisons (Tukey-Kramer HSD test) were conducted with the p values < .05.

RESULTS AND DISCUSSION: It was concluded that the lateral trunk tilt-angle over 90º indicates that the trunk is tilted to the contra-lateral side of the throwing arm. On the other hand, when the angle is under 90º, this demonstrates that a pitcher tilts his trunk to the throwing arm side. The mean of the lateral trunk tilt was 120º $\pm$ 6º and is consistent with the previous studies (Escamilla et al., 1998; Fleisig et al., 1995a). In following sub-sections, please note that the 120º condition can be substituted for the original.

Elbow kinetics. Figure 2 shows the maximum elbow medial force for each condition. From 80º to 100º of the lateral trunk tilt angle, no difference was observed. Over 100º of the lateral trunk tilt, the maximum elbow medial force tended to increase as the lateral trunk tilt angle increased. Significant differences were found between 130º and 80º, 90º, 100º conditions.

Figure 3 shows the maximum elbow varus torque for each lateral trunk tilt condition. This showed a similar pattern to the elbow medial force. Generally, it increased as a function of the lateral trunk tilt. Several significant differences were found, as shown in Figure.



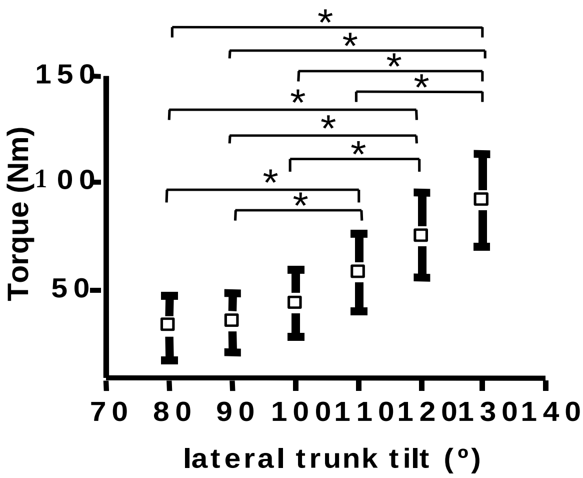


Figure 2 – Maximum elbow medial force. **Figure 3 – Maximum elbow varus troque.**

According to the pilot study, angle conditions from 80º to 100º, corresponded with the lateral trunk tilt angle for the sidearm pitchers. From the results of this study, it was suggested that the less lateral trunk tilt functioned to depress the elbow kinetics rather than to increase it. Using the data from Fleisig's study (1994) of the significant positive relationship between the maximum shoulder horizontal adduction and the maximum elbow medial force combined, the greater elbow force for the sidearm pitchers may be induced by the shoulder horizontal adduction movement, but not by the trunk tilt.

Shoulder kinetics. Figure 4 shows the maximum shoulder shear force. The shoulder shear force decreased as the lateral trunk tilt increased up to 110º. Significant differences were found between 80º and 110º and between 80º and 120º.
Figure 5 shows the maximum shoulder proximal force. Any significant differences were not found. It seemed to be irrelevant to the lateral trunk tilt.
In the pilot study investigating two professional underhand pitchers, greater shoulder anterior forces were demonstrated. The results in the current study were in agreement with the pilot study. The lateral trunk tilt angles at the ball release for the underhand pitchers in the pilot study were 65º and 80º, respectively. The shear force of 80º condition was 35% greater than that of the 120º condition. Lesser lateral trunk tilt may induce a greater shear force.

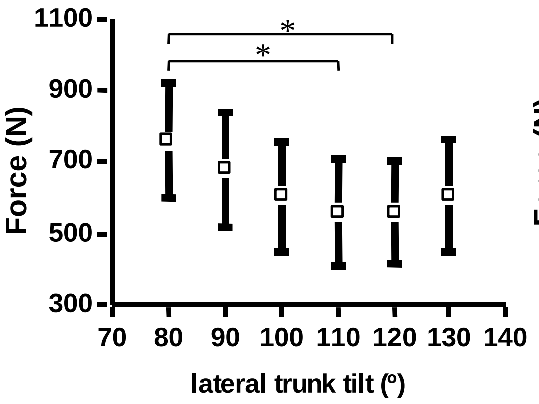


Figure 4 – Maximum shoulder shear force.

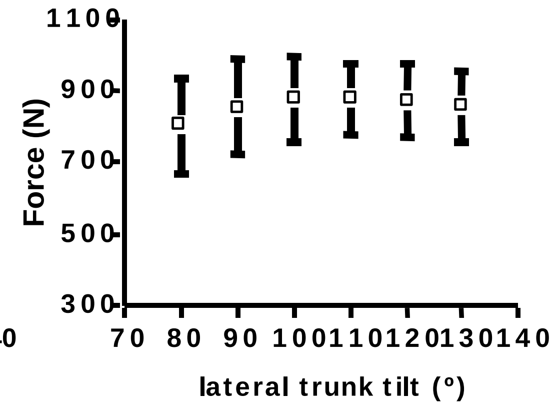


Figure 5 – Maximum shoulder proximal force.

CONCLUSION: From the results of the current study on the influence of the lateral trunk tilt angles during pitching on the joint kinetics, it was suggested that less trunk tilt did not increase the elbow joint kinetics, conversely it was decreased. On the other hand, less trunk tilt increased the shoulder shear force. Although the greater resultant force is not always consistent with the greater joint stress, careful consideration should be given to these facts. The method used in this study is not the most direct approach to elucidate the mechanism of the higher incidence of symptoms in the sidearm pitcher's elbow. However, the results of this study were useful in the elimination of one of the possible reasons.

REFERENCES:

Albright, J.A., Jok I,P., Shaw, R., & Albright, J.P. (1978). Clinical study of baseball pitchers: Correlation of injury to the throwing arm with method of delivery. *American Journal of Sports Medicine,* **6**, 15-21.

Ae, M., Tang, H.P., & Yokoi, T. (1992). Estimation of inertia properties of the body segments in Japanese athletes. *Biomechanism*, **11**, 23-33.

Escamilla, R.F., Fleisig, G.S., Barrentine, S.W., Zheng, N., & Andrews, J.R. (1998). Kinematic comparison of throwing different types of baseball pitches. *Journal of Applied Biomechanics*, **14**, 1-23.

Feltner, M. and Dapena, J. (1986). Dynamics of the shoulder and elbow joints of throwing arm during a baseball pitch. *International Journal of Sport Biomechanics*, **2**, 235-259.
Fleisig, G.S. (1994). *The biomechanics of baseball pitching.* Unpublished doctoral dissertation. Birmingham, AL: University of Alabama at Birmingham.
Fleisig, G.S., Andrews, J.R., Dillman, C.J., & Escamilla, R.F. (1995a). Kinetics of Baseball Pitching with Implications About Injury Mechanisms. *American Journal of Sports Medicine*, **23**, 233-239.
Fleisig, G.S., and Barrentine, S.W. (1995b). Biomechanical Aspects of the elbow in sports. *Sports Medicine and Anthroscopy Review*, **3**, 149-159.
Winter, D.A. (1990). *Biomechanics and motor control of human movement*. (2nd ed.) New York: Wiley Intersceince.
Jensen, R. K. (1978). Estimation of the biomechanical properties of three body types using a photogrammetric method. *Journal of Biomechanics,* **11***,* 349-358.