A METHOD FOR ESTIMATING ELBOW VARUS TORQUE USING ONLY A BASEBALL WITH AN EMBEDDED SENSOR

Shohei Shibata[a*], Kohei Mimura[a], Takatsugu Shimana[a], Akira Maeda[b], Masafumi Fujii[b], Chiharu Suzuki[b], and Masahiro Kageyama[c]

[a]Mizuno Corporation, Osaka, Japan;
[b] National Institute of Fitness and Sports in Kanoya, Kagoshima, Japan;
[c]Hosei University, Tokyo, Japan

Currently, to measure the elbow varus torque during baseball pitching, it is necessary to attach markers and sensors to the body. The purpose of this study is to develop the method for estimating elbow varus torque by only a baseball with an embedded sensor, and examine the accuracy. Eight baseball pitchers threw a four-seam fastball with maximum effort. The varus torque was estimated using one-link-segment model by an accelerometer and gyro sensor placed in the baseball. The Intraclass Correlation Coefficients between the maximum values of the varus torque calculated by the proposed method and the values calculated by the motion capture system was high (ICC(3,1) = 0.73).This result indicates that proof of concept by one-link model is success and warrants future research to potentially develop a system with greater accuracy.

KEYWORDS: ELBOW INJURIES, SENSOR BALL, ONE-LINK-SEGMENT MODEL

INTRODUCTION: Elbow joint injuries are one of the most common disorders in baseball pitching. In fact, the rate of pitchers requiring reconstruction of the medial ulnar collateral ligament (UCL) of the elbow continues to increase, and nearly 25 % of Major League Baseball (MLB) and 15 % of active Minor League Baseball (MiLB) players have undergone the procedure at some point during their careers (Conte et al., 2015). Anz et al. (2010) indicated that the magnitude of varus torque (maximum elbow varus torque) in the maximum external rotation during the pitching motion may be an indicator of UCL injury. Thus, the measurement of varus torque during the pitching motion is thought to be effective for non-invasive screening for risk of elbow injuries.

Traditionally, elbow varus torque has been calculated by inverse dynamics using marker-based motion capture (Feltner et al., 1986). In recent years, the miniaturization and low cost of sensors has made it possible to use wearable sensors that are attached to the arm for measurement (Kyle et al. 2019). However, both of these methods require markers and sensors to be attached to the body, which is expected to cause a sense of constraint to the pitcher. In order to acquire data more closely resembling the actual pitching motion, it is hoped that non-additional equipment will be needed.

We developed a baseball with an embedded sensor equipped with a 12-axis sensor system. By using this ball, it is possible to acquire data such as acceleration and angular velocity of the ball without any contact with the body. Thus, this study had two objectives: (a) developing the method for estimating elbow varus torque by only a baseball with an embedded sensor (b) examining the accuracy of the proposed method.

METHODS:

Eight male baseball pitchers (age, 19 ± 2 years; weight, 76 ± 8 kg; height, 1.76 ± 0.05 m) participated in the experiment. All participants provided informed consent prior to participation. All the participants threw to a catcher located behind a home plate placed 18.44 m from the pitching rubber. Each participant threw 10 trials for a four-seam fastball with maximum effort. The trial with the highest velocity pitch for each pitcher was selected for analysis

The participants threw a baseball with an embedded sensor (MA-Q, Mizuno Corp., Japan) (Fig. 1). The sensor-embedded baseball had the same mass (0.145 kg) and material (cowhide, cotton thread) as a normal hardball. The sensor-embedded baseball was equipped with a 12-axis sensor system: a three-axis accelerometer, three-axis gyroscope, three-axis high-range accelerometer, and three-axis high-sensitivity magnetic sensor (MI sensor, Aichi Steel Corp., Japan). The data were recorded in microcomputer and sent to a smartphone via Low Energy Bluetooth. Four reflective markers were attached to the surface of the baseball. Reflective markers with a diameter of 9.5 mm were attached to the baseball, fingers, and back of the hand, and reflective markers with a diameter of 13 mm were attached to the other segments (forearm, upper arm, and trunk). The measurements were taken by synchronizing two systems in order to improve the recognition accuracy of the reflective markers attached to the body and the ball. First, to track the reflective markers on the trunk, upper arm, and forearm, we used an optical 3D motion analysis system (Mac3D, Motion Analysis Corp) with a sampling frequency of 500 Hz. In addition, an optical 3D motion analysis system consisting of a total of 13 infrared cameras with a sampling frequency of 1000 Hz was used to track the reflective markers on the back of the hand, fingers, and ball on the throwing limb side. MATLAB (MathWorks Inc.,Massachusetts, USA) was used to conduct data processing and analysis. To reduce the noise of data, both positional data and sensor data were smoothed using singular spectrum analysis (Alonso et al., 2005).

In the one-link-segment model by a baseball with an embedded sensor, the ball, finger, palm and forearm are considered to be a single rigid body (the one-segment model), and the segment moves freely in space due to the force and force-couple/moment applied to its proximal end. The one-segment model including the ball, fingers, palm, and forearm was defined as one link from the elbow joint center to the wrist joint center. The one-segment model was defined as the mass of the hand and forearm calculated from de Leva (1996) plus the mass of the ball. The length of one-segment model was estimated from the height for easy use in the field. The center of mass (COM), moment of inertia and radius of gyration were calculated from de Leva (1996). The varus torque estimated by the proposed method was calculated as

$$a_{elbow} = A - \dot{\omega} \times L - \omega \times (\omega \times L) - g \tag{1}$$

$$a_{com} = a_{elbow} + COM(\dot{\omega} \times L) + \omega \times COM(\omega \times L) \tag{2}$$

$$T_{elbow} = I_{forearm}\dot{\omega} + COM\left[L \times \left(m_{forearm}a_{com} - m_{forearm}g\right)\right] \tag{3}$$

where a_{elbow} denotes the translational acceleration at elbow joint, A denotes measured acceleration at ball, L denotes the length of forearm, ω denotes resultant angular velocity at ball, COM denotes the ratio of COM of one-segment model, a_{com} denotes acceleration at the position of COM of one-segment model, T_{elbow} denotes resultant elbow joint torque and $I_{forearm}$ denotes moment of inertia at forearm. Because the elbow joint coordinate system cannot be defined in the one-segment model, the valgus and varus torque and the extension and flexion torque cannot be decomposed, so the resultant torque of the valgus and varus torque and the extension and flexion torque is used as an index to represent the varus torque of the elbow joint in the one-segment model.

In four-link-segments model calculated by the three-dimensional motion capture system, we applied the finger model of Shibata et al. (2021), in which the moving the point of application between the fingers and the ball. The wrist and elbow joint torque were calculated in order from the metacarpophalangeal (MP) joint torque at the fingers by inverse dynamics calculation (Shibata et al., 2018).

The maximum values of the varus torque from foot contact phase to 50 ms before ball release (the maximum external rotation) calculated using each model were recorded for each trial and compared. To confirm the accuracy of the varus torque, Intraclass Correlation Coefficients (ICC) was calculated between the maximum values of the varus torque calculated by the proposed method and the maximum valued of the varus torque calculated by the motion capture system (Mocap). Differences between the varus torque by the proposed method and the varus torque by Mocap were analyzed using paired t-tests. We judged the level of significance as $p < 0.05$. To detect system bias, Blant-Altman analysis was conducted and effect sizes was calculated.

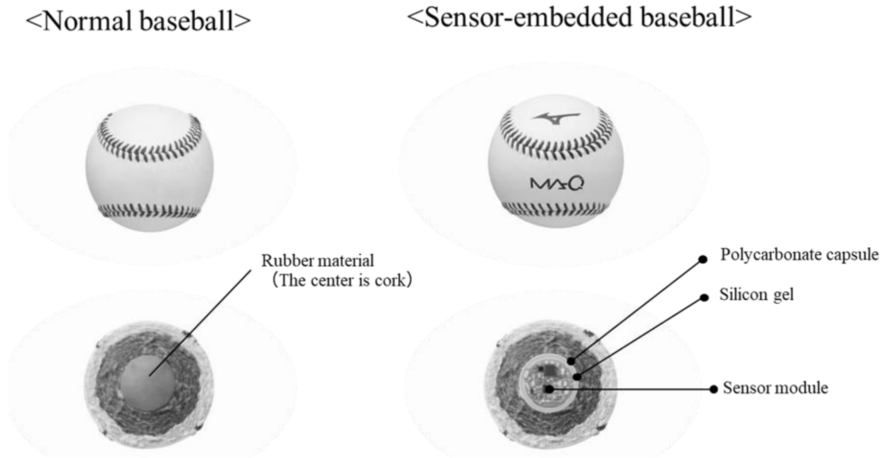

Figure 1: Structure of a regular hardball and a sensor-embedded baseball.

RESULTS: The mean ball velocity was 33.8 ± 2.5 m/s. The ICC(3,1) between the maximum values of the varus torque calculated by the proposed method and the maximum values of the varus torque calculated by Mocap was high (ICC(3,1) = 0.73). In addition, there were no significant differences between the maximum values of the varus torque (47.2 ± 11.9 N・m) calculated by the proposed method and the maximum values of the varus torque (61.6 ± 25.9 N・m) calculated by Mocap ($p > 0.05$). Effect sizes was 0.67. From Blant-Altman analysis, bias and precision in proposed method was -14.4±18.7. The proportional errors showed a significant negative correlation for proposed method (r = -0.79, p < 0.05).

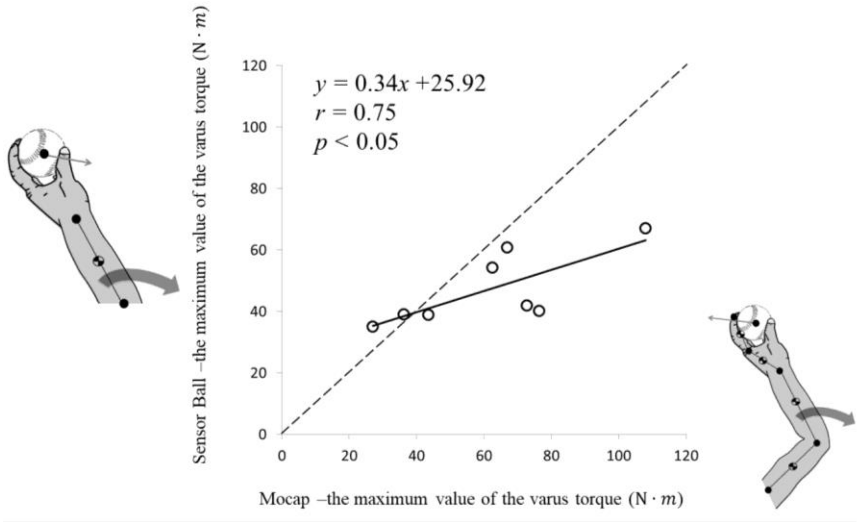

Figure 2: The relationship between the maximum values of the varus torque calculated by the proposed method and the maximum values of the varus torque calculated by Mocap. A schematic drawing of the one and four segment was drawn for each.

DISCUSSION: This study had two objectives: (a) developing the method for estimating elbow varus torque by only a baseball with an embedded sensor (b) examining the accuracy of the proposed method. The mean varus torque in this study (61.6 ± 25.9 N·m) was higher than those of a previous study in which collegiate-aged baseball pitchers participated (55 ± 12 N·m) (Fleisig et al, 1999). The reason for the large estimate of the maximum in this study may be due to the difference in the models applied. Shibata et al. (2018) reported that the wrist joint torque was underestimated in the conventional model (three-segment-model) as the previous study due to the effect of the acceleration term of the ball. The acceleration term of the ball was added to the elbow joint torque in four-segment-model, which is thought to have resulted in a large value. Also, Shibata et al. (2018) indicated the reliability of wrist torque by finger model was 82 %, has a good accuracy. This result supports the validity of four link segment model. The mean fastball velocity in this study (33.8 ± 2.5 m/s) was similar to those of a previous study in which collegiate-aged baseball pitchers participated (33.8 ± 1.7 m/s) (Jinji and Sakurai, 2006). This similarity between the results of this study and those of previous studies support the validity of the kinematic data recorded by the baseball with an embedded sensor.

The ICC(3,1) between the maximum values of the varus torque calculated by the proposed method and the maximum values of the varus torque calculated by Mocap was high (ICC(3,1) = 0.73) On the other hand, the Bland-Altman analysis of this study confirmed that there is proportional error. This indicates that the error increases as the ball speed increases. This error may be due to the fact that the upper arm motion was not taken into account in one segment. In fact, shoulder internal angular velocity increased with the ball velocity (Hirashima et al., 2006). It was considered that the translational acceleration of the elbow joint included the error as a result of the error of the relative angular velocity in one-segment. Finally, the inertia force and the motion-dependent moment included the error, resulting in varus torque mismatch. In addition, the small sample size is a limitation of this study. For further accuracy, future studies need to develop the model considering the motion of the upper arm with more pitchers.

CONCLUSION: This study had two objectives: (a) developing the method for estimating elbow varus torque by only a baseball with an embedded sensor (b) examining the accuracy of the proposed method. The result showed that the ICC (3,1) of the varus torque was high. On the other hand, it was indicated that there is proportional errors. This result indicates that proof of concept by one-link model is success and warrants future research to potentially develop a system with greater accuracy using more pitchers data.

REFERENCES

Alonso, F, J, Del Castillo, J, M & Pintado, P. (2005). Application of singular spectrum analysis to the smoothing of raw kinematic signals. *Journal of Biomechanics*, 38, 1085–1092.

Anz, A.W, Bushnell, B.D, Griffin, L.P, Noonan, T.J, Torry, M.R & Hawkins, R.J. (2010). Correlation of torque and elbow injury in professional baseball pitchers. *American journal of sports medicine*, 38 (7), 1368-1374.

Conte, S.A, Fleisig, G.S, Dines, J.S, Wilk, K.E & Aune, K.T. (2015). Patterson-Flynn N, ElAttrache N. Prevalence of ulnar collateral ligament surgery in professional baseball players. *American Journal of Sports Medicine*, 43 (7), 1764-1769.

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics*, 29, 1223–1230.

Feltner, M, Dapena, J. (1986). Dynamics of the shoulder and elbow joints of the throwing arm during a baseball pitch. *International Journal of Sport Biomechanics*, 2(4), 235-259.

Fleisig GS, Barrentine SW, Zheng N, Escamilla RF, Andrews JR. (1999). Kinematic and kinetic comparison of baseball pitching among various levels of development. *Journal of Biomechanics*, 32(12),1371-1375.

Hirashima M, Kudo K, Watarai K, Ohtsuki T. (2006). Control of 3D limb dynamics in unconstrained overarm throws of different speeds performed by skilled baseball players. *Journal of Neurophysiology*, 97(1), 680-91.

Jinji, T. and Sakurai, S.(2006). Direction of spin axis and spin rate of the pitched baseball. *Sports Biomechanics*, 5, 197-214.

Kyle, J, B, Joseph, A, M, Alex, C, Kyle, E, L,John, O, S & Michael, E, O. (2019). Exploring wearable sensors as an alternative to marker-based motion capture in the pitching delivery. *PeerJ,*7(e6365), 1-13.

Shibata, S., Inaba, Y., Yosihoka, S., and Fukashiro, S.(2018). Kinetic analysis of fingers during aimed throwing. *Motor Control*, 22, 406-424.

Shibata, S, Kageyama, M, Inaba, Y, Yoshioka, S, and Fukashiro, S. (2021). Kinetic analysis of the wrist and fingers during fastball and curveball pitches. *European Journal of Sport Science*, 1-10.