©Journal of Sports Science and Medicine (2008) 7, 223-228
http://www.jssm.org

Research article

The role of shoulder maximum external rotation during throwing for elbow injury prevention in baseball players

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Abstract
The objective of the present study was to examine whether the passive range of shoulder external rotation (ER), the maximum shoulder external rotation angle (MER) during throwing, and the ratio of MER to ER are related to the incidence of the elbow injury. A mixed design with one between-factor (a history of the elbow injury) and two within-factors (ER and MER) was used to analyze the difference between baseball players with and without a history of medial elbow pain. Twenty high school baseball players who had experienced the medial elbow pain within the previous month but who were not experiencing the pain on the day of the experiment were recruited (elbow-injured group). Another twenty baseball players who had never experienced the medial elbow pain were also used for testing (control group). MER during throwing, ER, and the ratio of MER to ER were obtained in both of the group. A Mann-Whitney test was used for the group comparison ($p < 0.05$). The ratio of MER to ER was significantly greater in the elbow-injured group (1.52 ± 0.19) than that in the control group (1.33 ± 0.23) ($p = 0.008$). On the other hand, there was no statistical significance in MER and ER between two groups. The findings of the study indicate that MER/ER relation could be associated with the incidence of the elbow injury in baseball players.

Key words: Throwing, shoulder, maximum external rotation, elbow valgus stress, prevention.

Introduction

It has been accepted that medial elbow pain is caused by repetitive stress in throwing motion to baseball players. Medial elbow pain may be related to various pathologic conditions such as overuse-syndrome of medial muscle group, medial epicondylitis, and medial ligament sprain (Brogdon and Crow, 1960; Slocum, 1968). Prevention of such injury must be important since the medial elbow injuries may lead to irreversible conditions such as an elbow joint deformity. Although, a number of studies have been conducted in an effort to decrease the number of medial elbow pain incidence (Fleisig et al., 1995; Lyman et al., 2001, 2002; Olsen, et al., 2006; Reagan, et al., 2002; Sabick, et al., 2004a); high prevalence of the injury still remains a significant problem, which was reported by Magra et al. (2007) in their review article that 18-69% of baseball players aged between 9 and 19 had experienced medial elbow pain.

When switching from the late cocking phase to the acceleration phase, forearm movement lags behind the movement of its proximal segment. This phenomenon is called “lagging back” (Kreighbaum and Berthels, 1996). Elbow valgus stress caused by the lagging back is thought to be a leading cause of elbow injury (Slocum, 1968). Therefore, we need to identify possible risk factors contributing to the increase of the valgus stress so that we will prevent elbow injury from occurring. Werner et al. (1993) demonstrated that the degree of shoulder external rotation in throwing motion was associated with the amount of elbow valgus stress. In addition, valgus stress on elbow was found to increase in transition from the late cocking phase to the acceleration phase in the throwing motion (Feltner, 1989; Sabick, et al., 2004b; Werner, et al., 2002), with the greatest stress occurring near the point of maximal external rotation (MER) (Feltner and Dapena, 1986; Fleisig, et al., 1995). Since elbow valgus stress was a consequence of shoulder internal torque during throwing, greater elbow valgus may occur at MER when a range of motion of shoulder external rotation (ER) is restricted. In addition, the ER on the throwing shoulder was reported to be from 100º to 140º (Bigliani, et al., 1997; Crockett, et al., 2002, Downar and Sauers, 2005; Meister, et al., Reagan, et al., 2002; Sethi, et al., 2004), whereas the MER was reported to be from 160º to 180º (Sabick, et al., 2004b; Dillman, et al., 1993; Fleisig, et al., 1999; Papas, et al., 1985). Therefore, the shoulder may exhibit a greater MER in throwing than that which the ER suggests.

In view of these previous findings, the ER restriction and excessive MER may increase the elbow valgus stress in throwing. In addition, the elbow valgus stress could also be increased by either excessive MER with proper ER or normal MER with restricted ER. Therefore, to investigate the factors that contribute to elbow valgus stress, an investigation into ER, MER and their relation on the incidence of the medial elbow pain needed to be conducted.

The purpose of the present study is to demonstrate the contribution of MER/ER relation on elbow injury occurrence by comparing between groups of high school baseball players with and without a history of the medial elbow pain. We hypothesized that a baseball player who has a history of medial elbow pain would show the smaller ER, the greater MER and the ratio of MER to ER

Received: 30 October 2007 / Accepted: 06 March 2008 / Published (online): 01 June 2008

in throwing.

Methods

Twenty high school baseball players who had experienced medial elbow pain induced only by throwing within the previous month prior to the experiment but were not experiencing the pain on the day of the experiment were recruited as elbow-injured group. Careful consideration was required in this type of selection of the subject. If the subject displayed the elbow pain while being tested, it would be difficult to decide whether the shoulder kinematic data was the cause or the result of the medial elbow pain. In addition, if the pain subsided well before the day of the experiment, we might not be able to identify the pathological throwing mechanics in the result. Therefore, we recruited baseball players who had a recent history of medial elbow pain, but did not have any elbow pain on the day of the experiment as the elbow injured group.

A clinical examination was conducted carefully according to the predetermined procedure. After the history of the elbow injury was asked by an experienced physical therapist, the presence of tenderness and motion pain on the elbow were examined. Joint laxity and any sign of joint abnormality were then evaluated by orthopedic tests. Those who displayed any tenderness, subjective pain during motion (active, passive, or both), and / or abnormal joint laxity on elbow joint in the clinical examination were excluded from the experiment. Three subjects had missed several sessions of baseball practice due to the medial elbow pain, although no structural abnormality was found in a roentgen examination. The average age, height, weight, years of baseball experience were 17.1 ± 0.6years, 1.70 ± 0.05cm, 63.8 ± 12.7kg, and 7.7 ± 1.6years, respectively. The elbow-injured group consisted of 3 pitchers, 1 catcher, 12 infielders, and 4 outfielders. In addition, another group of twenty high school baseball players who had never experienced any medial elbow pain was recruited as the control group. The average age, height, weight, and years of baseball experience in the control group were 17.0 ± 0.7years, 1.70 ± 0.07cm, 62.2 ± 7.4kg, and 7.7 ± 2.4years, respectively. The control group consisted of 4 pitchers, 1 catcher, 8 infielders, and 7 outfielders. Prior to the experiment, all subjects signed their names on the informed consent form approved by the Hiroshima University Ethics Committee.

ER was measured bilaterally by a 2D-3D motion analyzer (Frame-DIAS II, DKH, Tokyo, Japan). Subjects were placed in a sitting position with shoulder abduction and elbow flexion angle at 90º. The standard manual muscle testing manoeuvre for ER is used in a supine position. However, since the posture in throwing was an upright position, the sitting position must have simulated actual throwing motions more accurately. After the shoulder was passively moved until the maximum position, the measurement angle was determined by one experienced physical therapist. Excellent intra-tester repeatability was confirmed with intraclass correlate coefficient (ICC) (ICC = 0.97). The shoulder position was captured by a digital video camera and was transferred to a personal computer for the further analysis. During the ER measurement, the passive force of 20 Newton (N) was applied to the distal end of forearm. The magnitude of the passive force was monitored in a hand-held dynamometer (Micro FETII, Hoggan Health Ind. Inc., USA). Lumbar extension was not observed during the measurement.

Data collection for the throwing was performed on an outdoor baseball field. After a warm-up period, the subject executed five throwing trials at his maximum effort. The throwing distance, throwing target, outfit, and equipment used in this experiment were selected to simulate real practices or games. A throwing distance of 27.43m, the regulation distance between bases, was used. The throwing target was a baseball glove held in front of the catcher's chest. In addition, the subject held a glove on his non-throwing hand and wore a pair of baseball uniform pants, spiked shoes, and a sleeveless shirt with a hole on the back for marker placement during the testing.

Reflective markers were placed at the bony landmarks of subjects' upper body: acromion process, the dorsal side of the distal end of the humerus and forearms, and the spinous process of the 8th thoracic vertebrae (Figure 1).

Direct Linear Transformation (DLT) method

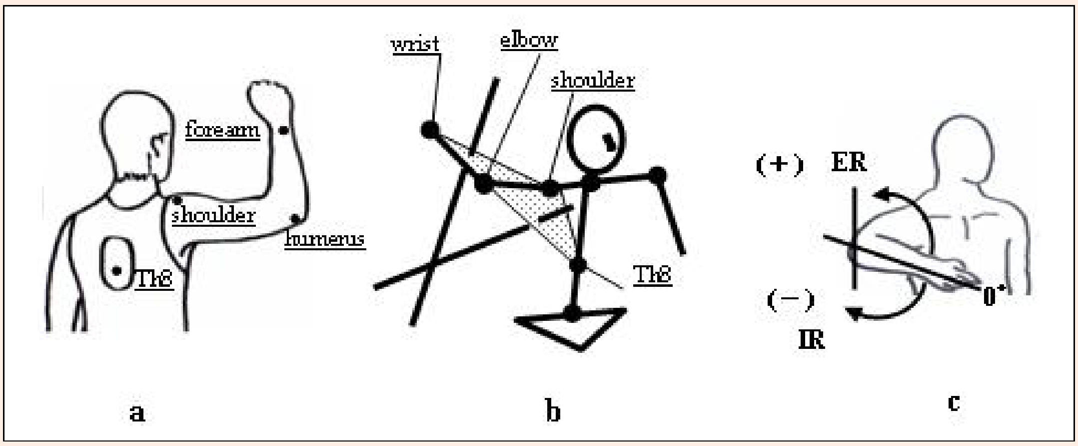

Figure1. Marker placement (a), computation method for maximum external rotation angle during throwing (b), and the expression of shoulder external rotation angle (c).

Table1. Descriptive data of the kinematic variables in the elbow-injured and the control groups. Data are means (±SD).

	ROM in ER			
	Throwing side	Non-throwing side	MER	Ratio
Elbow injured	114.5 (12.7)	106.1 (10.6)	175.2 (36.2)	1.52 (.19)
Control	120.5 (14.1)	114.1 (10.8)	159.2 (26.6)	1.33 (.23)

(Abdel-Aziz and Karara, 1971) was performed to establish three-dimensional (3D) coordinates of the shoulder complex in throwing with a 2D-3D motion analyzer (Frame-DIAS II, DKH, Tokyo, Japan). The throwing attempt in which the ball was the most accurately controlled to the target was used for the analysis. Two high-speed video cameras (HSV-400, NAC Image Technology, Inc., Tokyo, Japan) were used to collect the throwing motion data sampled at 200Hz. These cameras were located to the right and left rear of the subject. Throwing motion data for the three throws was transferred to a personal computer for marker digitizing. The reflective makers were automatically tracked by the motion analyzer.

The MER was determined by a kinematic model with two segments. One was described by lines between the markers on dorsal side of distal forearm (wrist marker), elbow joint (humerus marker) and acromion process of the throwing shoulder (shoulder marker), and the other was described by lines between markers on the humerus marker, the shoulder marker, and the spinous process of the 8th thoracic vertebrae (Th 8 marker) (Figure 1a). First, two normal unit vectors projected from the two segments were computed. Inner product between the normal unit vectors and their cosine angle was then defined as the external rotation angle of the shoulder (Figure 1b). Our MER computation method allows us to obtain a net external rotation angle of shoulder complex without an influence of thoracic and lumber movements. Shoulder external rotation angle where the planes intersected at an angle of 90º was defined as zero degree. The direction of external rotation was expressed as a positive value in this study (Figure 1c).

The ratio of MER to ER was calculated, which was expressed as MER divided by the ER. This proposed index was designed to assess the magnitude of the valgus stress imposed on the elbow.

A Mann-Whitney test was performed to compare ER on throwing shoulder, MER in throwing, and the ratio of MER to ER between the two groups. In order to determine whether the degree of ER represented inherent or acquired characteristics of the subjects, ER on non-throwing shoulder was also compared between the two groups. We used commercial statistical ad-in software (Statcel, OMS, Japan) for the statistical analysis. Statistical significance was defined as an alpha level of 0 .05 in this study.

Results

Velocity through the jump divided by race pace (v/p) was the kinematic data of the elbow-injured and the control groups was presented in Table 1. The average ER of the throwing shoulder was 114.5 ± 12.7º in the elbow-injured group and 120.5 ± 14.1º in the control group. There was no significant difference between the groups (Figure 2). The average ER of the non-throwing shoulder was 106.1 ± 10.6º in the elbow-injured group and 114.1±10.8º in the control group. The elbow-injured group showed significantly smaller ER on the non-throwing shoulder than that in the control group ($p = 0.026$) (Figure 3). The throwing shoulder showed a significantly greater ER than that in the non-throwing shoulder in the elbow-injured group. Difference in the ER of the throwing shoulder was not statistically significant.

The average value of the MER was 175.2 ± 36.2º in the elbow-injured group and 159.2 ± 26.6º in the control group. There was no significant difference between the groups (Figure 4).

The average ratio of MER to ER was 1.52 ± 0.19 in the elbow-injured group and 1.33 ± 0.23 in the control group. The ratio was significantly greater in the elbow-injured group than that in the control group ($p = 0.008$) (Figure 5).

Discussion

It has been suggested that lagging back produces valgus force on the elbow in throwing. Therefore, the primary

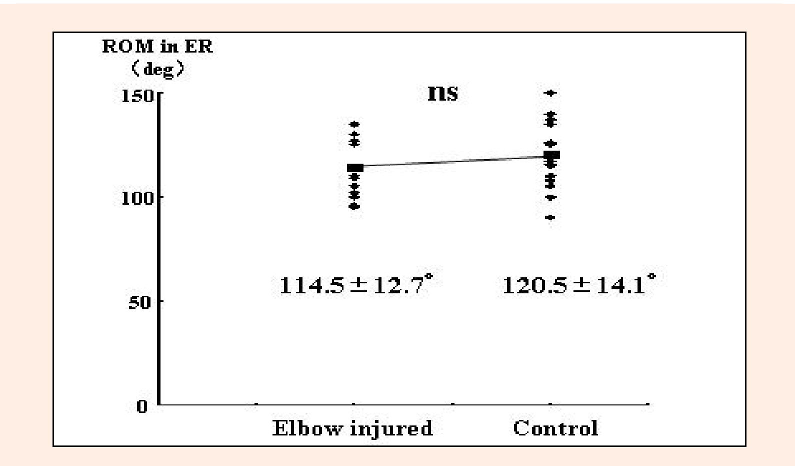

Figure2. Range of motion of shoulder external rotation in throwing shoulder.

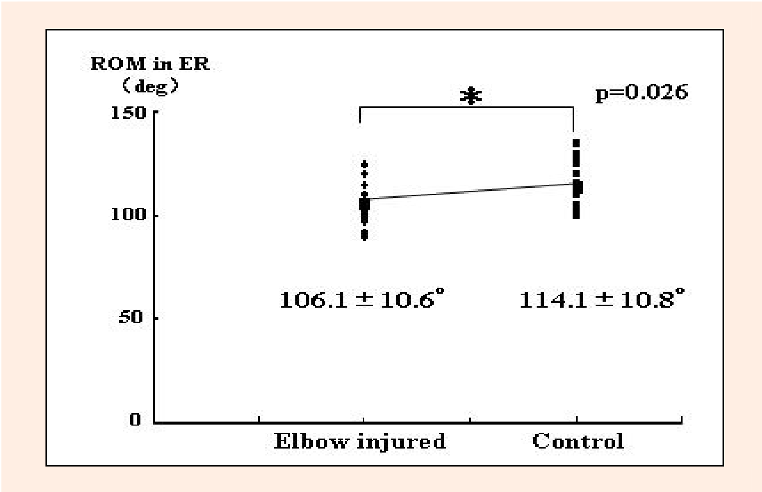

Figure3. Range of motion of shoulder external rotation in non-throwing shoulder.

purpose of the present study was to determine whether MER/ER relation was related to the elbow injury experience of baseball players. A greater valgus stress occurs when the MER is relatively great in relation to the ER of shoulder external rotation. Therefore, restriction of ER in shoulder external rotation, excessive MER during throwing, and/or the combination of those could increase elbow valgus stress in the throwing motion.

In our present study, ER of the non-throwing shoulder was significantly smaller in the elbow-injured group than that in the control group, whereas ER of the throwing shoulder tended to be greater in the control group than that in the elbow injured group though the difference was not statistically significant. It has been reported that the ER of the throwing shoulder tends to be greater than the non-throwing shoulder in competitive baseball players (Bigliani, et al., 1997; Crockett, et al., 2002; Meister, et al., 2005; Pappas, et al., 1985; Sabick, et al., 2004b), which is thought to be a result of adaptation to repetitive throwing (Bigliani, et al., 1997; Crockett, et al., 2002; Papas, et al., 1985). The present findings suggest that the ER in elbow-injured group may have been inherently smaller than that in the control group. Then, the ER of the throwing shoulder may have increased by repetitive throwing during their baseball careers.

Elbow valgus stress is supposed to be greater when greater MER compared to ER occurs in throwing. In the present study, the ratio of MER to ER was significantly greater in the elbow-injured group. These findings suggest that the elbow was subjected to a greater amount of valgus stress in the elbow-injured group, which may be associated with the history of the medial elbow pain.

The acceleration phase in throwing consists of shoulder internal rotation and elbow extension (Feltner, 1989; Papas, 1985). Previous studies have suggested that the stress on the elbow joint was significantly greater when elbow extension and internal rotation were overemphasized during acceleration phase (Werner et al., 1993; Feltner and Dapena, 1986). The current result also suggests that throwing mechanics that is characterized by excessive shoulder external rotation during the cocking phase may lead to medial elbow pain.

It could have been necessary to quantify the elbow valgus stress during the throwing in order to validate the ratio of MER to ER as an index that represents the magnitude of valgus stress on the elbow. However, the current biomechanics models do not include anatomical and functional individualities of shoulder joint into the equation for the calculation of elbow valgus stress during throwing. From our clinical experience, we believe that ER and

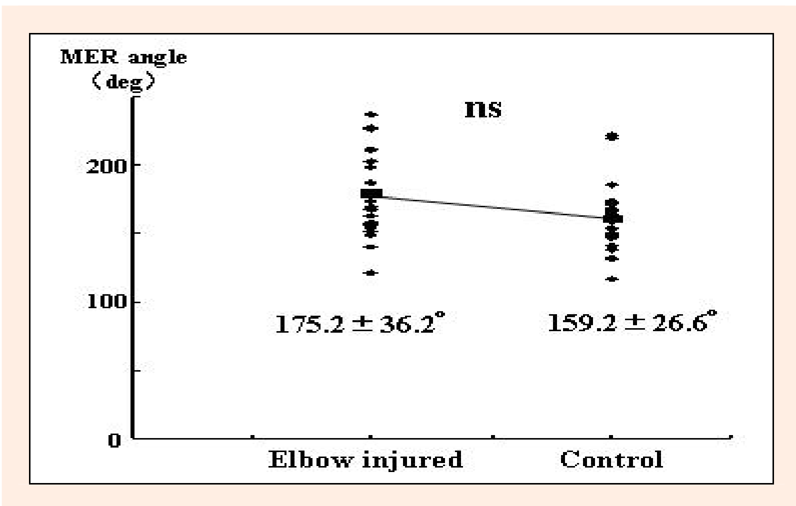

Figure 4. Maximum external rotation angle during throwing.

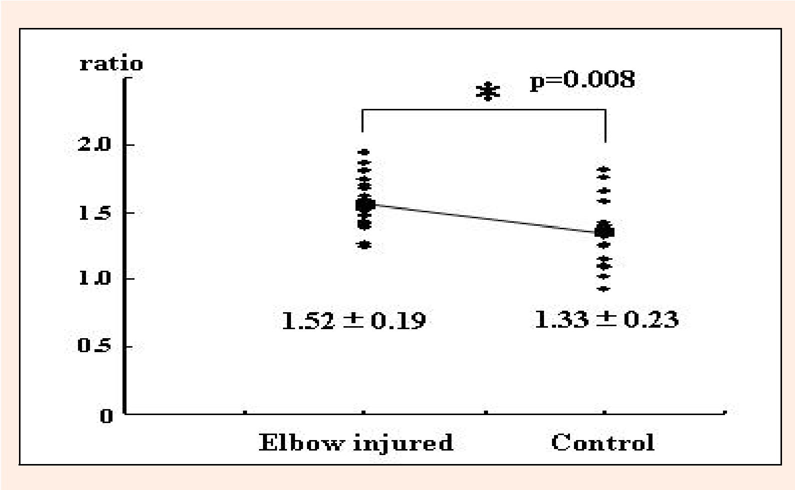

Figure 5. The ratio of maximum external rotation angle (MER) to passive ROM of external rotation of the shoulder.

other anatomical individualities could largely affect the amount of imposed stress on elbow. Therefore, we conducted only kinematic analysis of the baseball throwing motion in this study. Since a high correlation between valgus stress and MER in throwing has been reported in the previous studies (Sabick, et al., 2004b), we believe that ratio of MER to ER reasonably reflects the amount of the valgus stress on elbow.

Conclusion

ER and MER in throwing, and the ratio of the MER to the ER were compared between high school baseball players with and without a history of throwing elbow injuries. The elbow-injured group demonstrated significantly greater ratio of MER to ER than that in the control group. This finding suggests that the throwing mechanics that is characterized by great MER in relation to ER could be associated with medial elbow pain in high school baseball players.

Acknowledgments
Thank you to Ira and Mary Lou Fulton for funding this study.

References

Abdel-Aziz, Y.I. and Karara, H.M. (1971) Direct linear transformation from comparator coordinates in close-range photogrammetry. In: *Proceedings American Society of Photogrammetry Symposium on Close-Range Photogrammetry*. Falls Church, VA: American Society of Photogrammetry Symposium on Close-Range Photogrammetry.1-19.

Bigliani, L.U., Codd, .P.T., Connor, P.M., Levine, W.N. and Littlefield, M.A. and Hershon, S.J (1997) Shoulder motion and laxity in the professional baseball player. *American Journal of Sports Medicine* **25**, 609-613.

Brogdon, B.G. and Crow, N.E. (1960) Little leaguer's elbow. *American Journal of Roentgenology* **83**,671-675.

Crockett, H.C., Gross, L.B. Wilk, K.E., Schwartz, M.L., Reed, J., O'Mara, J., Reilly, M.T., Dugas, J.R., Meister, K., Lyman, S. and Andrews, J.R. (2002) Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. *American Journal of Sports Medicine* **30**, 20-26.

Downar, J.M. and Sauers, E.L. (2005) Clinical measurement of shoulder mobility in the professional baseball player. *Journal of Athletic Training* **40**, 23-29.

Dillman, C.J., Fleisig, G.S. and Andrews, J.R. (1993) Biomechanics of pitching with emphasis upon shoulder kinematics. *Journal of Orthopaedic Sports Physical Therapy* **18**, 402-408.

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

Feltner, M.E. (1989) Three-dimensional interactions in a two-segment kinetic chain. PartII:Application to the Throwing Arm in Baseball Pitching. *International Journal of Sports Biomechanics* **5**, 420-450.

Fleisig, G.S., Andrews J.R., Dillman C.J. and Escamilla, R.F. (1995) Kinetics of baseball pitching with implications about injury mechanisms. *American Journal of Sports Medicine* **23,** 223-239.

Fleisig, G.S., Barrentine, S.W., Zheng, N., Escamilla, R.F. and Andrews J.R. (1999) Kinematic and kinetic comparison of baseball pitching among various levels of development. *Journal of Biomechanics* **32**, 1371-1375.

Kreighbaum, E. and Berthels, K.M. (1996) *Biomechanics: A qualitative approach for studying human movement.* 4th edition. Boston, MA: Allyn & Bacon. 335-354.

Lyman, S., Fleisig, G.S., Waterbor, J.W., Funkhouser, E.M., Pulley, L., Andrews, J.R., Osinski, E.D. and Roseman, J.M.(2001) Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Medicine and Science in Sports and Exercise* **33**, 1803-1810.

Lyman, S., Fleisig, G.S., Waterbor, J.W., Andrews, J.R. and Osinski, E.D. (2002) Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *American Journal of Sports Medicine* **30**, 463-468.

Magra, M., Caine, D. and Mafulli, N. (2007) A review of epidemiology of paediatric elbow injuries in sports. *Sports Medicine* **37**, 717-735.

Meister, K., Day, T., Horodyski, M., Kaminski, T.W., Wasik, M.P. and Tillman, S. (2005) Rotational motion changes in the glenohumeral joint of the adolescent/ little league baseball player. *American Journal of Sports Medicine* **33**, 693-698.

Sethi, P.M., Tibone, J.E. and Lee, T.Q. (2004) Quantitative assessment of glenohumeral translation in baseball player. *American Journal of Sports Medicine* **32**, 1711-1715.

Olsen, S.J., Fleisig, G.S., Dun, S., Loftice, J. and Andrews, J.R. (2006) Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *American Journal of Sports Medicine* **34**, 905-912.

Pappas, A.M., Zawacki, R.M. and Sullivan, T.J. (1985) Biomechanics of baseball pitching. *American Journal of Sports Medicine* **13**, 216-222.

Reagan, K.M., Meister, K., Horodyski, M.B., Werner, D.W., Carruthers, C. and Wilk, K. (2002) Humeral retroversion and its relationship to glenohumeral rotation in the shoulder of college baseball player. *American Journal of Sports Medicine* **30**, 354-360.

Sabick, M.B., Torry, M.R., Kim, Y.K. and Hawkins, R.J. (2004a) Humeral torque in professional baseball pitchers. *American Journal of Sports Medicine* **32**, 892-898.

Sabick, M.B., Torry, M.R., Lawton, R.L. and Hawkins, R.J. (2004b) Valgus torque in youth baseball pitchers. A biomechanical study. *Journal of Shoulder and Elbow Surgery* **13**, 349-355.

Slocum, D.B. (1968) Classification of elbow injuries from baseball pitching. *Texas Medicine* **64**, 48-53

Werner, S.L., Fleisig, G.S., Dillman, C.J. and Andrews, J.R. (1993)

Biomechanics of the elbow during baseball pitching. *Journal of Orthopaedic Sports Physical Therapy* **17**, 274-278.
Werner, S.L., Murray, T.A., Hawkens, R.J. and Gill, T.J. (2002) Relationship between throwing mechanics and elbow valgus in professional baseball pitchers. *Journal of Shoulder and Elbow Surgery* **11**,151-155.

Key points

- It is accepted that the greatest elbow valgus stress appears at the position of shoulder maximum external rotation (MER) in the acceleration phase of the throwing movement. As a consequence, shoulders with restricted range of motion of external rotation (ER) compensate with a valgus stress on their elbow joints.
- In this study, we evaluated the relation between MER and ER of shoulder in players with/without elbow injuries.
- The result of this study demonstrated that the elbow injured group showed significantly greater MER/ER relation than the control group.
- The current finding suggests that great MER combined with the ROM restriction may be one of the risk factors to cause medial elbow pain in baseball players.

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