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ORIGINAL

Biomechanical Evaluation of Elbow Moment in Pitching Types according to the Throwing Speed: A Pilot Study

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Objective: The incidence rate of elbow ulnar collateral ligament injuries is dependent on the throwing speed or pitching type, especially in adolescent baseball players. However, mixed results have been reported due to a lack of controlled biomechanical analysis. Thus, the purpose of this study was to investigate the biomechanical analysis of the elbow in relation to throwing speed and pitching type.

Method: Four overhead type high-school baseball players were recruited for this study. The participants were asked to throw balls with different types of pitch and speed. While the throwing speeds were measured, each pitching moment of the elbow was recorded. Descriptive statistics, frequency analysis, mean comparison analysis, and Pearson's correlation analysis were performed in order to examine differences in peak varus and valgus moment during pitching motion in the elbow in all throwing speed and pitching types.

Results: There was no significant difference in physical characteristics, throwing speed, and momentum variability among all players. The mean varus moments were 44.38±1.55 Nm, 48.83±1.66 Nm, and 48.94±0.95 Nm, and the moment gaps between varus and valgus were 7.36±3.25 Nm, 7.44±2.02 Nm, and 7.36±2.62 Nm in fastball, curveball, and slider ball, respectively. The varus moment was higher in the curved and slider balls than in the fastballs, and there was no significant differences between the varus moments regarding the pitching type. However, the increase in valgus moment and decrease in moment gap according to throwing speed was significantly increased in the slider ball (r=0.718 and -0.591, respectively).

Conclusion: The possibility of elbow injury caused by the valgus moment or moment gap increases more rapidly in slider balls as the speed increases. Based on our results, appropriate pitching guidelines should be suggested to prevent ulnar ligament injuries, especially in adolescent baseball players.

Keywords: Pitching type, Throwing speed, Varus and Valgus moment, Injuries

INTRODUCTION

The number of baseball players is continuously increasing, and in the United States, more than 6 million youths are part of a baseball team (Dun, Loftice, Fleisig, Kingsley & Andrews, 2008). People that participate in baseball games use their entire body, especially their dominant arms, which affects their ability to exert significant power. However, baseball players may suffer from musculoskeletal injuries due to excessive or repetitive movements. The number of injuries is increasing yearly in young baseball pitchers and many risk factors for elbow injuries have been identified (Aguinaldo & Chambers, 2009). In recent studies, it was reported that 25% of all young pitchers complained of elbow pain after two seasons and that 50% of them would appeal to pain on the shoulder or elbow after one season (Lyman, Fleisig, Andrews & Osinski, 2002; Lyman et al., 2001).

In order to achieve a better baseball career in the future, high-school students try to throw faster balls or use different pitching techniques. However, since their bones are not yet fully ossified, they can potentially increase the risk of damage due to excessive and repetitive stress. Additionally, due to the increasing rates of injury, the number of young players who have undergone surgeries is becoming similar to that of professional players that have a low rate of injury risk. Limiting the number of pitches to prevent injury to young players has been debated. The Korean Baseball Softball Association limits high-school pitchers to 105 throws per day, and the Japanese High School Baseball Federation will also limit 500 pitches per week in 2020. Compared to the previous 5 year period, the number of surgeries almost doubled in professional players, quadrupled in college students, and sextupled in high-school students (Nissen et al., 2009).

Previous studies have shown that the increased risk of shoulder and elbow pain in young pitchers is related to the pitching type, pitch number, and pitching mechanics (Lyman et al., 2002; Lyman et al., 2001; Fleisig et al., 2006; Petty, Andrews, Fleisig & Cain, 2004; Fleisig, Barrentine, Zheng, Escamilla & Andrews, 1999). Previous studies have suggested that arm pain and surgery are not only related to the number of pitches but also associated with the pitching type (Aguinaldo & Chambers, 2009). Furthermore, it was suggested that breaking balls are more dangerous, since the risk of shoulder pain is increased by 52% when pitching a curveball, and the risk of elbow pain increases by 86% when pitching a slider (Werner, Fleisig, Dillman & Andrews, 1993). In later studies, higher throwing speed was associated with an increased risk of elbow injuries in young and adult pitchers. Dun et al. evaluated the technique of fastballs, curveballs, and changeups in 12-year-old pitchers and found that fastballs caused higher loads on the shoulders and elbows of young pitchers (Dun et al., 2008). Additionally, high throwing speed is considered to be a characteristic of talented young pitchers, suggesting that the best pitcher may be most vulnerable to injury (Fleisig et al., 2006). Major league pitchers tend to be particularly vulnerable due to the throwing speed and the repetitive stress during their professional careers (Aguinaldo & Chambers, 2009). This supports the explanation that larger muscle forces must be generated to achieve faster speeds and that larger shear forces can be generated by a larger rotational torque.

A recent study found that excessive use of the arm especially at an early age, when throwing breaking balls may be associated with ulnar collateral ligament damage (Dun et al., 2008; Okoroha et al., 2019). The radical increase in ulnar collateral ligament (UCL) injuries is a concern for young baseball players and the mass media. Currently, 26% of young pitchers experience elbow pain during a season, and reconstructive surgery for the ulnar collateral ligament of young players is increasing (Lyman et al., 2001). Medial elbow injury may be the result of acute rupture or micro- and degenerative damage that is repeated frequently over several seasons, and the high varus torque of the medial elbow may alter the appearance of the ulnar collateral ligament and increase the risk of injury. In previous studies, the incidence of elbow collateral ligament injuries was considered to be dependent on throwing speed and pitching type. However, there has been a lack of controlled biomechanical analysis regarding varus and valgus moments in combination of throwing speed and pitching type. The comprehensive analysis between ulnar valgus and varus momentum, while variation of throwing speed and pitching type would possibly reveal the substantial stress loaded on the elbow.

Therefore, the aim of this study was to provide biomechanical basis data of young baseball pitchers by examining the varus and valgus moments in relation to the pitching type.

METHODS

The current study is a pilot study. Four high-school overhead-type baseball players participated in this study. To recruit the participants, the researcher advertised the purpose and method of the study throughout the Korean Olympic Committee. Recruited participants were screened by investigating their medical history and questionnaires on the basis of the following inclusion criteria: high-school baseball player with overhand pitching, more than 6 years of pitching experience as a dedicated baseball player, and no musculoskeletal or neurologic problems. The objectives and requirements of the study were explained to all participants, and they provided signed informed consent.

The participants were asked to provide general information including age and career as a baseball player. Their height (1.82 ±0.04 m), weight (79.95±5.89 kg), body mass index (24.29± 0.88 kg/m^2), arm length (0.80±0.03 m), and leg length (0.96± 0.03 m) was measured. After collecting the general information of the participants, they were asked to throw fastball, slider, and curveballs. During pitching, to analyze pitching movement in the elbow with respect to throwing speed and type, all subjects had reflective markers attached to the lateral superior tip of both the accordion, lateral humeral epicondyle, greater fem-

Table 1. The biomechanical data of the participants

	Fast ball	Curveball	Slider ball	*p*
Throwing speed (km/h)	95.99±2.00	78.61±2.34	82.20±2.74	.000
Varus moment (Nm)	44.38±1.55	48.83±1.66	48.94±0.95	.048
Valgus moment (Nm)	37.01±2.44	41.39±2.52	41.57±2.56	.359
*Moment gap (Nm)	7.36±3.25	7.44±2.02	7.36±2.62	0.05

*Moment gap: difference between varus and valgus moments

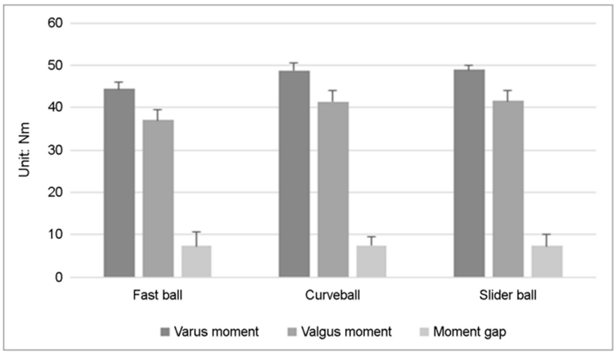

Figure 1. Comparison of the elbow moments and moment

Table 2. The correlation between throwing speed and moments

	Fast ball	Curveball	Slider ball
Varus moment	0.335	0.387	0.300
Valgus moment	0.350	0.434	0.718**
Moment gap	-0.104	-0.224	-0.591*

*$p<.05$, **$p<.01$

oral trochanter, lateral femoral epicondyle, lateral malleolus, proximal end of 3rd metartarsal, ulnar styloid of a hand wearing a glove, ulnar styloid, radial styloid, and distal end of the 3rd metacarpal of a pitching hand. The subjects wore sneakers and shorts and warmed up until they felt ready to throw a ball. After warming up, the subjects pitched a catcher sitting 18.44 m away from the indoor round. They were asked to throw three fastballs, slider balls, and curveballs at submaximal and maximal speeds. The speeds of all pitches were measured using a Bushnell Speed Radar Gun (Bushnell, Germany). Pitching movement was also monitored using a high-speed automatic digital system (Motion Analysis Corporation, Santa Rosa, California). The system collected data at 250 Hz using 12 cameras, and the collected data were converted to kinematic parameters and kinetic parameters, peak varus and valgus moment of the elbow, using KinToolsRT (Motion Analysis Corporation, Santa Rosa, California). The moment gap was defined as the difference between the varus and valgus moments. Before collecting the kinetic data, all cameras were set up, including pitching motion, and the global frame was created on the basis of the calibration frame using seed and wand calibration methods to set the 3-dimensional coordinate system. Position data were with the 4th-order Butterworth low-pass filter with a cutoff frequency of 15 Hz was used to eliminate the noise from movements or labeling errors.

General information was analyzed by descriptive statistics. Descriptive statistics and Pearson's correlations were performed in order to examine differences in varus and valgus moment in elbow in all throwing speed and pitching types.

RESULTS

The demographic data of the participants are shown in Table 1. There was no significant difference in exercise career, physical characteristics, and throwing speed among the participants. The throwing speed was fastest in the fast ball and slowest in the curveball. In all pitching types, the varus moment was greater than the valgus moment. The amount of varus moment was significantly greater in the curve (48.83±1.66 Nm) and slider balls (48.94±0.95 Nm) than fastballs (44.38±1.55 Nm) (p= 0.048). There was no significant difference in the moment gap, which is defined as the difference between varus and valgus, regardless of pitching type (p=0.05) (Table 1 and Figure 1).

There was a low correlation between the varus moment and throwing speed in all pitching types. The valgus moment had a moderate correlation with the throwing speed in slider balls

(r=0.718). Additionally, there was a moderate negative correlation between the moment gap and throwing speed in slider balls (r=-0.591) (Table 2).

DISCUSSION

Due to the increasing demand for players to throw faster balls to achieve a better baseball career, the prevalence of elbow injuries is increasing yearly, especially in adolescents (Aguinaldo & Chambers, 2009; Lyman et al., 2002). In previous studies, a high number of pitches, pitching type, arm fatigue, age, weight, and insufficient rest for each season are factors associated with elbow pain and damage (Aguinaldo & Chambers, 2009; Lyman et al., 2002). Unlike single traumatic situations, arm injury in baseball is due to accumulated micro-damage during repetitive pitching, and increased stress on the throwing arm contributes to overuse injury (Dun et al., 2008; Levin, Zheng, Dugas, Cain & Andrews, 2004; Fleisig, Andrews, Dillman & Escamilla, 1995; Dillman, Fleisig & Andrews, 1993). In many reports, the number of elbow injuries increases with increasing throwing speeds, regardless of the pitching type (Lyman et al., 2002; Lyman et al., 2001; Fleisig et al., 2006; Petty et al., 2004; Fleisig et al., 1999). Among them, shoulder and elbow injuries occur mainly in overhead throwing, and up to 50% of professional pitchers experience shoulder or elbow pain (Aguinaldo & Chambers, 2009). In a prospective study of 476 young pitchers aged 9~14 years, the curveball was found to be associated with a 52% increased risk of shoulder pain, and the slider ball was found to be associated with an 86% increased risk of elbow pain (Fleisig et al., 2006).

The kinematics of the curveball are different from those of the fastball. The curveball is associated with greater forearm supination, less wrist extension, and a shorter stride. Some studies have suggested that rapid supination exposes the elbow to high valgus moments and may lead to increased injury rates. One of the concerns regarding the risk associated with throwing a curveball is forearm pronation and supination movement during the pitching cycle. The forearm remained more supinated during the cocking and acceleration phases of each curveball as compared with the fastball (Lyman et al., 2002). Peter et al. demonstrated that valgus moment can be explained by the variance in maximum shoulder external rotation angle and thus injuries (Chalmers et al., 2017). Having a more extended elbow at specific time points has been linked to greater shoulder distraction force and greater elbow valgus moment. However, in other studies, when comparing professional baseball pitchers, showed mixed results. Although there was a strong association between ball speed and varus moment within an individual pitcher, higher velocity may not necessarily indicate higher elbow-varus torque (Chalmers, Erickson, Ball, Romeo & Verma, 2016).

In addition, Flesig et al. compared the reaction rates of fastballs, curveballs, sliders, and change-ups. They found that joint loads were similar during fastballs, curveballs, and sliders and significantly less in changeups (Lyman et al., 2002; Fleisig et al., 1999). Various throwing speeds, different levels of participants, unclear throwing speed, and pitching type relationship appear to be the causes of the mixed results. Moreover, other confounding factors, such as anthropometrics and pitching mechanics, should also be considered in explaining these results further.

Although there was no mound to throw and progressed indoors, the actual pitching speed of the players did not come out, and we also observed similar results where the varus moment was higher in the curveballs and slider balls than the fast balls (Table 1). There was no significant increase in the varus moment according to throwing speed in all pitching types. However, the moment gap, the difference between varus and valgus moment, had a moderate negative correlation with the throwing speed of the slider balls (Table 2). These findings suggest that the possibility of elbow injury increases more frequently with the speed in slider balls when there is a decrease in the moment difference.

Previous biomechanical studies have shown that the valgus moment is as high as 64 Nm during the late cocking and acceleration phases of the throwing motion, which is the period in which most elbow injuries occur (Dun et al., 2008; Aguinaldo & Chambers, 2009; Lin et al., 2007). Elbow ulnar collateral injury can occur in this late cocking phase, which appears to be the amount of the varus moment or possibly the small moment gap. Theoretically, when the varus moment increases or the moment gap decreases, repetitive valgus forces on the throwing elbow place significant stress on that joint. The throwing motion creates a large moment because a large tension and compression force are generated in the soft tissue inside the elbow (Werner, Murray, Hawkins & Gill, 2002). Varus torque moments are required to prevent valgus overload, which is produced by tension of the UCL and flexor-pronator muscles in accordance with compression of the radiocapitellar joint.

Although the mean valgus moment of the slider balls in our study (41.57±2.56 Nm) did not exceed the previous cutoff value (64 Nm). However, the potential risk of elbow injuries might increase when repetition of pitching due to a decrease in the moment gap.

Although several *in vitro* studies have revealed the cutoff value of the ulnar moment by measuring the varus-valgus tension, it could not be suggested as a standard guideline in a clinical setting (Lin et al., 2007; Seiber, Gupta, McGarry, Safran & Lee, 2009; Udall, Fitzpatrick, McGarry, Leba & Lee, 2009). In one computed modeling study, muscle-tendon contributions of valgus strength and power also cause a potential injury to the elbow (Buffi, Werner, Kepple & Murray, 2015). In general, pitch count limits and rest recommendations exist according to age by many baseball associations. They suggested daily maximal pitches and resting periods. However, they did not define the precise speed level and pitching type according to individuals. In addition, different levels of players and physical characteristics regarding anthropometrics and pitching mechanics could also result in different results.

In our study, we evaluated the biomechanical ulnar moment regarding the combination of the pitching type and throwing speed. There was a moderate correlation between valgus moment and throwing speed, and a negative moderate correlation between the moment gap and throwing speed in slider balls. These results could be meaningful in suggesting the potential risk when a combination of pitching type and throwing speed in adolescent baseball players.

However, there are several limitations to our study prior to the generalization of our data. First, we recruited a small number of pitchers, which might have a sampling bias. Second, the throwing speed in our study was slower than that of professional baseball pitchers, which appears to be insufficient to cause injuries or compensatory action to protect the elbow injuries. Third, we did not measure the momentum analysis according to the repetition of pitches. Fatigue of the players was also regarded as an important factor in elbow damage. As muscle fatigue, dynamic control of the pitch was reduced while a greater burden on the ulnar collateral ligament could be loaded.

CONCLUSION

The possibility of elbow injury can be caused by an increase in the varus or valgus moment and a decrease in the moment gap. In our study, slider balls showed a moderate correlation between valgus moment and throwing speed. In addition, there was a negative moderate correlation between the moment gap and throwing speed in slider balls. Based on our results, appropriate pitching guidelines should be suggested to prevent ulnar ligament injuries, especially in adolescent baseball players.

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