JSES Open Access 2 (2018) 115–119

Contents lists available at ScienceDirect

JSES Open Access

journal homepage: www.elsevier.com/locate/jses

Three-dimensional kinematic analysis of throwing motion focusing on pelvic rotation at stride foot contact

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ARTICLE INFO

Keywords:
Pitching mechanics
Kinetic
Kinematic
Motion analysis
Pelvic rotation
Opening up too soon
Throwing motion
Pitching motion

Level of evidence: Basic Science Study, Kinesiology

Background: Because the throwing motion can be considered a kinetic chain, pelvic and trunk motion should be included in the analysis. Early pelvic rotation during the throwing sequence has been reported to be a factor leading to overloading of the shoulder and the elbow. A large pelvic rotation angle at the stride foot contact (SFC) was thought to indicate early pelvic opening. This study examined the kinematic features in each motion segment associated with increased pelvic rotation at SFC in pitchers of various ages and competition levels.

Materials and methods: The study included 324 pitchers with various age/competition levels. Throwing motion was analyzed using an infrared-type motion capture system. In the assessment, pelvic rotation angle at SFC was adopted as a parameter for the timing of pelvic opening. Statistical analyses were performed for correlation between pelvic rotation and kinematic variables of other motion segments at the instant of SFC as well as the difference in kinematics between the groups of different levels.

Results: Most of the kinematic results were not significantly different among the 4 groups with different levels. The increase in the pelvic opening angle at SFC was significantly correlated with increased trunk bend to the nonthrowing arm side and decreased hip flexion angle on the throwing arm side.

Discussion and Conclusion: Early pelvic rotation in the throwing motion sequence, as manifested by increased pelvic rotation at SFC, was correlated with changes in kinematic parameters at other motion segments such as increased trunk tilt and decreased hip flexion.

Throwing injuries in baseball pitchers present a substantial problem affecting the player's performance. Therefore, prevention and management of throwing injuries based on an accurate understanding of the injury mechanism is critically important.[8,15,21,29,30] Numerous studies have investigated the factors related to the injury risk, including improper throwing mechanics, increased number of pitches and innings, throwing breaking balls, and fatigue.[4,6,17]

Previous biomechanical studies of the kinematic and kinetic factors relevant to throwing injuries have indicated several pathologic mechanics leading to shoulder and elbow overload such as excessive horizontal shoulder abduction and insufficient elbow flexion.[2,15,23] In addition to shoulder and elbow mechanics, throwing motion can be considered a kinetic chain, transmitting motion and energy from the lower extremities to the upper limb.[2,7,12] Therefore, analysis of pelvic and trunk motion is thought to also be important to understand the etiology of throwing injuries. Several studies have examined the effect of pelvic and trunk rotation on the upper extremity kinematics and kinetics.[1,3,5,19,20,24,27]

Among the kinematic features of the pelvis and trunk in throwing motion, Fleisig et al[8,11] first addressed the significance of timing of the pelvic/trunk rotation, stating that early pelvic rotation during throwing could result in an increased load at the shoulder and elbow. Unfavorable kinematic chain sequence characterized by the too early pelvic rotation was represented as "opening up too soon" phenomenon by Meister et al.[15] In previous studies, improper motion patterns in the trunk and the hip have also been analyzed as potential factors leading to overload at the shoulder and the elbow. Therefore, to prevent throwing injuries based on the concept of the kinematic chain, the relationship between the pelvic motion and kinematics of the other motion segments, such as upper trunk and upper extremities, should be included in the analysis.

In the "optimal" pitching motion sequence, the trunk rotation should be initiated around the timing of the stride foot contact (SFC).[1]

The Nobuhara Hospital and Institute of Biomechanics Institutional Review Board approved this study (No. E156).

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https://doi.org/10.1016/j.jses.2017.12.007

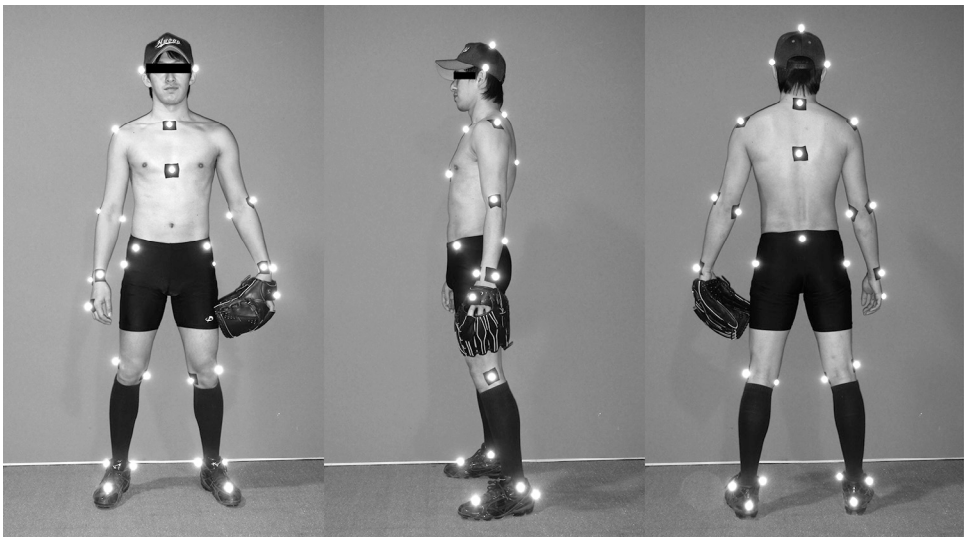

Figure 1 A total of 36 reflective plastic spheres were attached to the representative anatomic locations for the motion analysis.

Therefore, an increased pelvic rotation value in the transverse plane at the instant of SFC is thought to indicate the "opening up too soon" phenomenon.[27] In this study, we adopted the rotation angle of the pelvis at SFC as a parameter for the timing of pelvic rotation.

The purpose of this study was to examine the rotational kinematics and alignments of the trunk, the shoulder, and the hip (both lead and stance limbs) as well as the correlation between those kinematic results and increased pelvic rotation at SFC in pitchers of various ages and competition levels. The study hypotheses were as follows: first, there would be characteristic kinematic patterns in other motion segments, such as trunk and hip, which can be identified in association with early pelvic rotation at the SFC; and second, kinematic characteristics would be different among various ages/competition levels.

Materials and methods

Subjects

Motion analysis was performed for 324 pitchers with various competition levels. The study excluded pitchers who could not throw a fast ball due to shoulder or elbow pain. There were 146 youth-level pitchers (YP), 118 high school pitchers (HSP), 28 collegiate pitchers (CP), and 32 professional pitchers (PP). Age of the subjects ranged from 10 to 15 years in YP, 15 to 18 years in HP, and 18 years or older in CP and PP groups.[9] Semiprofessional and professional pitchers were included in the PP group, and amateur-level pitchers older than 18 years were included in the CP group. The average and range values for age, height, body weight, and ball speed in each group are described in Table I. All study participants read and signed a consent form before participation in this study.

Table I
The average and range values for age, height, body weight, and ball speed in each group

Group	No.	Age (y)	Height (cm)	Weight (kg)	Ball speed (km/h)
Youth	146	13.4 ± 1.2	165.4 ± 9.7	55.8 ± 10.1	100.3 ± 9.7
High school	118	16.3 ± 0.7	174.5 ± 5.2	66.9 ± 6.9	112.9 ± 6.7
College	28	20.1 ± 1.4	177.1 ± 5.2	72.3 ± 6.7	119.1 ± 5.2
Professional	32	25.1 ± 4.2	179.8 ± 5.7	79.0 ± 8.7	121.2 ± 6.0

Data are presented as mean ± standard deviation.

Motion analysis system

Throwing motion was analyzed using an infrared-type motion capture system (ProReflex MCU-500+; Qualisys, Göteborg, Sweden). Seven charge-coupled device cameras were set up around the official regulation-size pitching mound. For motion analysis, 36 reflective plastic spheres were attached to the subjects' skin on the representative anatomic locations according to the method used in previous relevant studies.[16,23] The location of each marker was determined by a physical therapist with adequate experience using this motion analysis system (Fig. 1).

The 3-dimensional (3D) positions of the markers during the motion were recorded at the rate of 500 Hz by the cameras. Ball speed was measured by a radar gun (SpeedMax2, Mizuno, Osaka, Japan). During the motion analysis, each subject was asked to throw a fastball at their maximum speed from the pitching mound to the home plate for a distance of 18.44 m (60'5") 3 times after a warm-up. The fastest pitch among the trials was considered to represent the "best" performance and used for the subsequent analysis[16,23] (Fig. 2).

Figure 2 Three-dimensional positions of the markers during throwing motion were recorded by the charge-coupled device cameras.