Three-dimensional Kinematic Analysis Of The Throwing Motion Focusing On Trunk Bending, Pelvic Rotation, And Horizontal Abduction Of The Shoulder.

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Introduction: Injuries related with throwing motion can be caused by suboptimal kinematics during throwing motion applying overloading to the musculoskeletal structures. Therefore, in order to construct effective preventive and therapeutic measures for these injuries and enable the injured player to return to play without recurrence, interventions to optimize throwing kinematics based on accurate evaluation of the throwing motion are mandatory. Among the potential etiologic factors in throwing kinematics, excessive shoulder horizontal abduction in late cocking and acceleration phase is considered to play a prime role inducing harmful mechanical stress in the shoulder.

In order to analyze the throwing motion based on a concept of kinematic chain, sequential kinematic and kinetic changes in pelvis, trunk, and upper extremity including shoulder should be evaluated. In the present study, three-dimensional kinematic analysis was performed for orientations of pelvis, trunk and shoulder in the late cocking and acceleration phases.

The purpose of the study was to investigate the relationship among the following three kinematic component: pelvic rotation, trunk motion, and horizontal abduction of the shoulder. We hypothesized that those kinematic components interact together and excessive pelvic rotation and trunk motion induce increase in shoulder horizontal abduction.

Methods: (Subjects)
Motion analysis was performed for 335 pitchers with various skill levels. Subjects who could not throw a fast ball due to shoulder or elbow pain were excluded from the study population. Age of the subjects ranged from 8 to 38 years. All study participants read and signed a consent form for participation in this study.

(Motion analysis system)
Throwing motion was analyzed using an infrared type motion capture system (ProReflexTM MCU-500+, Qualisys, Sweden). Seven CCD cameras were set up around the regulation-size pitching mound. For motion analysis, 36 reflective plastic spheres were attached to subject’s skin on the representative anatomical locations by an experienced physical therapist. Three-dimensional positions of the markers during the motion were recorded at a rate of 500 Hz by means of the cameras. Ball speed was measured by a speed gun (SpeedMax2, Mizuno, Japan). After a warm-up, each subject was asked to throw a fastball from a pitching mound over 3 appropriate trials and the fastest pitch was adopted for the subsequent analysis.

(Data analysis)
In the analysis, rigid-body model was constructed and the kinematic parameters were calculated based on the local coordinate system. The local coordinate system was established on each segment; 1) shoulder joint, 2) pelvis, and 3) femur. These coordinate systems were defined mathematically based on the localization of the anatomical landmarks. To describe six-degree-of freedom joint motion, Euler angle sequence was used. The throwing motion was divided into 4 phases by 5 points during the sequence: 1) wind up phase, 2) cocking phase, 3) acceleration phase, and 4) follow through phase. In the assessment, following kinematic variables were analyzed; pelvic rotation, bending and rotational trunk motion, and shoulder horizontal abduction/adduction angle. In statistical analysis, Spearman’s correlation coefficient was calculated to quantify the relationship between the parameters.

**Results:** Pelvic rotation angle at Ball Release (BR) was negatively correlated with trunk rotation angle at maximum external rotation (MER), and ball release (BR) (r=-0.71, and r=-0.75 respectively). Additionally, a significant correlation was detected between pelvic rotation angle and horizontal abduction angle of the shoulder at MER and BR (r=0.48, and r=0.53 respectively). Lateral bending angle of the trunk toward the non-throwing side at foot plant (FP) was positively correlated with horizontal abduction angle of the shoulder at MER (r=0.50).

**Discussion:** Negative correlation between the pelvic rotation and trunk rotation (increased pelvic rotation associated with reduced trunk rotation) seems to indicate that sequence of kinematic chain between pelvic and trunk motions is almost completed before MER. Additionally, excessive trunk lateral bending toward the non-throwing side at FP as well as excessive pelvic rotation at MER and BR may induce increase in horizontal abduction of the shoulder. Therefore, modification and optimization of the throwing motion focusing on lateral bending of the trunk toward non-throwing side and rotation of the pelvis at late cocking phase may be a key to reduction of horizontal abduction of the shoulder which is thought to be a prime factor leading to throwing injuries.

**Significance:** The results of this study can help construct systematic and effective approaches to prevention and management of shoulder problems in baseball pitchers through correction of throwing motion kinematics.
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