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THE CHARTERISTICS OF LOWER LIMB MOMENTS IN BASEBALL PITCHING

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The aim of this study was to examine the characteristics of lower limb moments in baseball pitching. Ten senior high school pitchers participated in this study (age: 16.7±0.7 yr; height: 179.1±5.8 cm; body mass: 73.7±8.9 kg). Ten VICON cameras (200Hz) and two Kistler force plates (1000Hz) fixed on a pitching mound were used to collect 3-D kinematic and GRF data. Three successful trials for each subject were used to compute lower limbs joint moments. The results indicated, for the pivot leg, ankle plantarflexor moment, knee and hip adductor moment are the key moments to transform energy to trunk and upper extremities by driving and rotating the knee. For the lead leg, ankle plantarflexor moment and hip flexor moment are the main joint moments to brake upper extremities by a knee extention during baseball pitching.

KEY WORDS: ground reaction force, moment, baseball, pitching

INTRODUCTION: Pitcher is an important role in a baseball game. Good pitcher can suppress the opponent's score, and increase the chance to win. The understanding of pitching mechanics is an important research. Previous studies focused on the upper extremities, no research have been reported on lower limb moments of pitchers on pitching mound. MacWilliams et al. (1998) measured the ground reaction force (GRF) from 7 pitchers. They found a high correlation between GRF and ball speed, but if the pitcher pushed too hard, they may lose balance and cannot produce high ball speed. They also found the GRF of lead foot is greater than pivot foot. The lead leg motion may play an important role in pitching. The GRF produced by both feet create the ankle, knee, and hip moments to accelerate the trunk, and upper extremities made a kinetic link to propel the ball. The study on the ankle, knee, and hip moments can help on understand the mechanism of pitching. The aim of this study was to examine the characteristics of lower limb moments in baseball pitching by using inverse dynamic method. We hoped the results can help coaches and pitchers to improve their pitching skill.

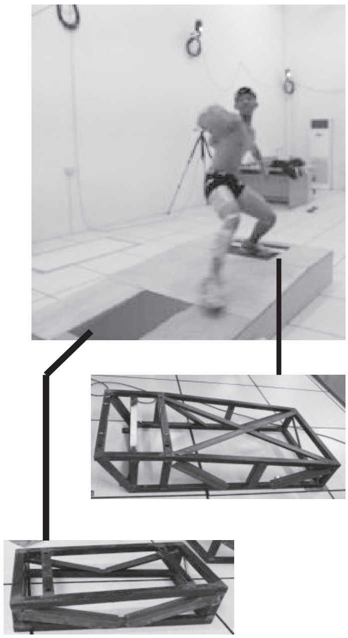

Figure 1: The structure of pitching mound. Two force plates were locked on these steel frames, then a wooden box covered it.

METHODS: Ten healthy senior high school pitchers (7 right hand, 3 left hand, 16-18 yr) who plays in Chinese Taipei student baseball federation participated in this study (age:16.7±0.7 yr; height: 179.1±5.8 cm; body mass: 73.7 ± 8.9 kg). All subjects were informed of the experimental procedures and gave their consent before participating. The study was approved by the local medical ethics committee. A VICON Motion capture system (Vicon Peak) with 8 digital cameras (F2) and two force platforms (Kistler 9281B) were used to collect 3-D kinematics (200 Hz) and force data (1000 Hz). Fifty-nine markers (8 mm in radius) were attached to the subject. These markers were attached according VICON plug-in-gait marker placement. The lower limb markers were used for compute the joint moments. The upper extremities markers were used for identify events and phases and future kinematic analysis. Four markers were attached on the ball to compute ball velocity (resultant velocity). Two steel frames were used to fix the force platforms. A wooden pitcher mound tile forward 4.8˚ with two holes cover on the platforms (Fig. 1). The subjects were asked to throw the baseball to a target (40*60cm,80cm high from ground.) attached to the safety net which is 3 m in front of the force platforms. The succeed trials were defined as the ball hit the target. Ten successful trials were collected, but only three trials with the fastest ball velocity were used analyzed. The force data were analyzed by power spectrum and 20Hz Butterworth digital filter were chosen for filtering the force data, and the kinematics data were filtered by a Butterworth digital filter with cut-off 13.4 Hz (Flesign, 1999). For easy comparison, the force data of lead foot were rotated 4.8˚ backward to make vertical axis perpendicular to the ground (MacWilliams et al., 1998), Kinetic data were computed by Visual3d using inverse dynamic method. Time was normalized with pitching duration (PD), defined as time from lead foot contact ground (Fc) to ball release (Rb). The coordinate of GRF were defined as anterior-posterior, medial-laterial, and vertical directions (MacWilliams et al., 1998). The joint moments were transformed into local anatomic coordinates.

RESULTS: The characteristics of GRFs and joint moments of pivot foot are shown in Figure 2 (a-d). In anterior-posterior and vertical directions, the GRF of pivot foot starts increasing when the lead foot at the highest point. The vertical GRF peaks first at -200% (840 N, about 1.14 BW). The anterior-posterior GRF peaks later at -85% (390 N, about 0.56 BW). The pivot foot slided off force platform and GRF disapperd after the lead foot contact ground (Fc)(Fig. 2a).
The ankle moments increased sharply after -300%. The plantarflexor moment peaked at -120% (94 N m). The other two moments were only 1/2 times of plantarflexor moment (Fig. 2b). The knee adductor moment increased at -200%, and peaks just before Fc (75%, 140 N m). The other two moments are 1/2 times of adductor moment (Fig. 2c). Similar results were observed on the hip joint, the hip adductor moment peaked at almost the same time with knee adductor moment. (-25%, 200 N m). The other two moments are only 1/3 times of adductor moment (Fig. 2d).
The GRF and joint moments of lead foot are shown in Figure 2 (e-h). The GRFs were observed after Fc. The peak vertical GRF (1174 N, about 1.63 BW) just before maximum shoulder external rotation (Me) and peak posterior GRF(582 N, about 0.82 BW) was observed almost at the same time. The medial-lateral GRF was very small (Fig. 2e). The lead leg joint moments all increased rapidly after Fc, and peaks near ball released. The maximum moment in ankle is plantarflexor moment. Its peak is 213 N m. The other two moments is less than 1/6 times of plantarflexor moment (Fig. 2f). The knee peak abductor moment is 77 N m and occured just before ball released. The other two moments are very small (Fig. 2g). The peak hip extensor moment is 250 N m also observed before ball released. The other two moment are only 1/2 times of flexor moment (Fig. 2h).

DISCUSSION: The throwing distance of 3m in this study was limited by the lab space. The computed mean ball velocity was 32.45±1.37 m/s, which is similar with previous study using the same level of pitchers(Flesign,1999). The ball velocity indicated the pitchers did their normal pitching performance during the experiment.
This study is the first research to document GRF and joint moments for both lower limbs during baseball pitching. MacWilliams et al.(1998) studied GRF of 10 pitchers. The patterns of GRF and peak values was similar with this study. (pivot leg vertical force (1.14 BW,1BW); anterior force (0.56 BW, 0.35 BW); leading leg vertical force (1.63 BW, 1.5 BW); posterior force (0.82 BW,0.72 BW)). This study supports their findings that GRF characteristic patterns of pitchers are similar, and the forces were concentrated in the plane defined by the direction of the pitch and the vertical axis.
By using the inverse dynamic method, ankle moment was affected by GRF and foot rotation. Due to the small foot moment of inertia, the GRF was the main factor affecting ankle joint moment. This may explain the ankle joint moment and the vertical GRF pattern have similar

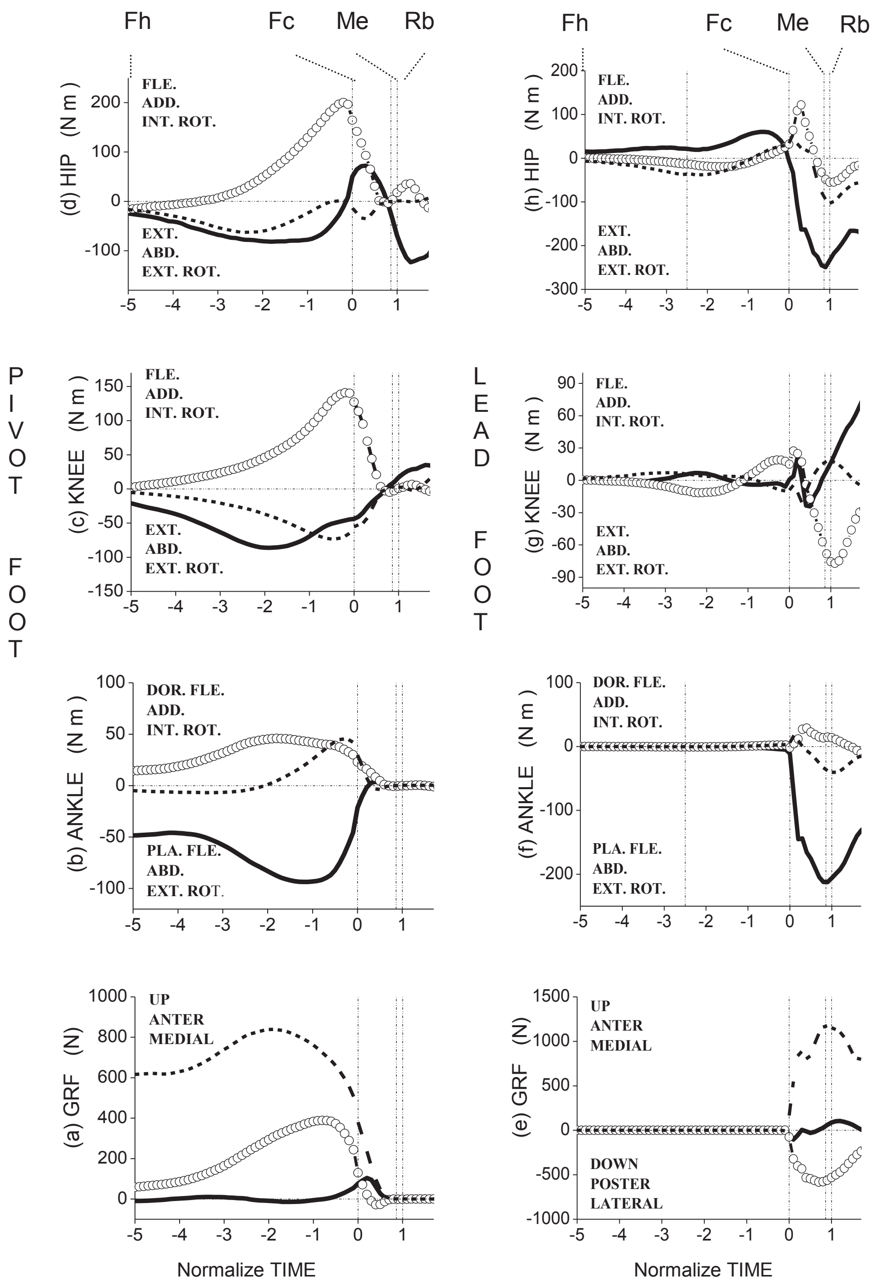

Figure 2: Pivot and leading foot GRF and joint moments the data is mean of 10 subjects. (flexion-extension and medial-lateral ▬▬, abduction-adduction and anterior- posterior ◦◦◦◦, internal-external and vertical – – –). Fh: lead foot at the hightest point. Fc: lead foot contacted ground. Me: maximum shoulder external rotation. Rb: ball released. Time was normalize by Fc-Rb (1=100%).

pattern. At that time, pitcher start transforming body forward. When the peak knee and hip joint moment appeared, the ankle moment become very small. At this time the knee are rotation sideward.The knee adductor moment used to decreased the shank's sideward rotation. The hip adductor moment balanced the knee moment and decreased the thigh's sideward rotation. The knee can only produce little adduction motion, So the sideward knee rotation was produced by hip rotation. That may result the knee and hip peak moments arrived at the same time just before the lead leg contacted the ground. In the proximal end of pelvic, the hip adductor moment in oppoite direction would help to accelerate pelvic to rotate to pitching direction. These results showed the stride phase have a drive and a rotation process. Through these two process, the kinetic energy tranfsferred from pivot foot to trunk and arms.
At the lead leg, the GRFs and three joint moments increased quickly after Fc. MacWilliams et al. (1998) found the lead foot anchors the body to balance forces generated in the trunk and upper extremities. During this phase, the foot anchors on the gorund, but the shank and thigh rotated in opposite direction to extend the knee joint. Combining with the lower limb movement, the ankle joint moment produced to balance the GRF and keep the foot stable. The opposite moment in shank's proximal end made shank rotation, so the lead leg doesn't produced much knee moment to balance it. The hip moment were produced to make the thigh rotation. The opposite moment in trunk's proximal end decelerated trunk's rotation. Masuo et al. (2001) found more knee extension would made a more stable lower limbs. This was agreed with our study. Accroding these result, the main joint moments were produced in ankle and hip to braking the upper extremities.

CONCLUSION: The characteristic patterns of pitching GRF and lower limb joint moments were identified. The GRFs were concentrated in the plane defined by the pitch and vertical direction. For the pivot leg, ankle plantarflexor moment, knee and hip adductor moment are the moments to tranform energy to upper extremities by driving and rotating the knee. For the lead leg, ankle plantarflexor moment and hip extensor moment are the main joint moments to brake upper extremities by a knee extention during baseball pitching.

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