KINETIC CHARACTERISTICS AND STRESSES OF THE JOINT ON THE LANDING LEG DURING THE LANDING PHASE OF SOFTBALL PITCHING

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The purpose of this study was by conducting the inverse dynamic method to investigate the joint reaction forces, net muscle joint moments and powers of the ankle, knee and hip during the softball pitch. Four elite softball pitchers experiencing world-class competition were acting as subjects in this study. A Peak high-speed camera (120Hz) and synthesized with a force plate (600Hz) was used to collect the relative parameters of landing leg during pitching. The results indicated that the extensors' eccentric muscle powers of knee and the flexors' concentric muscle powers of hip were the important ability for the softball pitching performance. In addition, the greater compressive and shear stresses which around the joint created during the landing phase would put a heavy load on soft tissue, ligament and tendon.

KEY WORDS: inverse dynamic, moment, power, stress, softball

INTRODUCTION: The softball pitcher is the most important player in the team. Force is an important aspect to the softball pitch. Great forces are produced from the lower limb driving against the ground and transferred it via the trunk to the pitching arm to perform the fastball pitching (Alderson & Elliott, 1999; Elliott, Grove & Gibson, 1988). To strengthen the lower extremity is an important factor of the softball pitch. The movements of lower extremity are composed of two major parts, the pushing leg was driving to against the pitcher's plate and the landing leg was to break it. At the moment landing leg contact to the ground, while the upper limb is accelerated to swing forward, the foot applied a force to slow the motion of lower limb and then halt the rotation of the trunk to transfer the energy to pitching arm (Hay, 1985; Elliott et al., 1988; MacWilliams et al., 1998). So the resistance of the landing leg is an important ability for the softball pitcher. However the survey by the author showed that Taiwan softball pitchers (N=37; High:1.67±0.05m; Weight:63.1±7.0kg□ Age:21±4years; Training years:7±4years) have a high percent injury (Lower limb:70.2□; Ankle:35□; Knee:43□; Hip and Waist: 46□) in landing leg. The potential injury during the activity must be evaluated via the measurement of external forces.

The purpose of this study was to investigate the kinetics of softball pitch. The joint reaction forces, net muscle joint moments and powers of the ankle, knee and hip was calculated by applying the inverse dynamic method. To seek the load of lower limb and the muscle activity of landing leg during the phase of pitch landing. The information would be useful for coach, physical education teachers, when they teaching the softball pitching technique. In addition, the result would be providing information to prevent the potential injury for softball pitchers.

METHODS AND PROCEDURES: Four female elite softball pitchers experiencing world-class competition was selected as subjects. The mean characteristics were shown in Table 1. A Peak high-speed camera (120Hz; 1/2000) was used to locate at 20m away from the subject to record the action of landing leg during pitching. A force plate (Kilster9287, 600Hz) was also synthesized to collect the horizontal and vertical ground reaction forces and center of pressure of landing leg during pitching. The experimental setup was shown in Figure1. The subject stood 2.0m away from the force plate to pitch fastball with windmill style while passed through the home plate over a distance of 12.19m. The landing leg stepped on the force plate. The experienced catcher determined the successful pitch. Three successful trials were collected for each subject. The trial that produced the highest release velocity was selected for kinetic analysis. Segment of data for foot, leg and thigh were taken from Dempster's method.

Data Processing: Four body landmarks (hip, knee, ankle and toe of landing leg) and one reference point were digitized and framed by Peak Motus system. A Butterworth Digital Recursive Filter was used to filtering the random noise during the digitizing process. The ground reaction forces were scaled and smoothed by using a second order low pass digital with cutoff frequencies of 30 Hz. The joint reaction forces and moments were calculated by using inverse dynamics process, where $\Sigma F_j=m_i \times a_j$ (F: Joint reaction force; m: mass of the segment; a: Acceleration of the CG of the segment) and $\Sigma M_i=I_i \times \alpha_i$ (M: Net muscle joint moment ; I: Moment of inertia of the segment about the axis through CG of the segment; α: Angular acceleration of the segment related to horizontal axis). The net muscle joint powers were calculated as the $P_i=M_i \times \omega_i$ (ω: Angular velocity of the joint). All kinetic parameters were normalize for body mass.

Table1 Subject Characteristics (N=4)

	Mean (±SD)
Age (years)	25.0±4.6
Height (m)	1.68±0.06
Weight (kg)	62.3±4.2
Training Years(years)	11.0±4.0

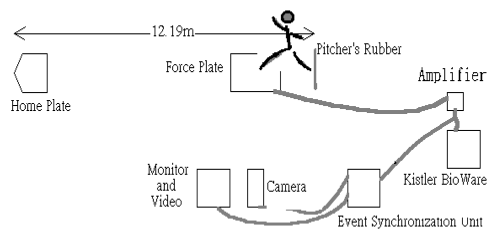

Figure1 - The experimental setup.

RESULTS AND DISCUSSION:

Net Muscle Joint Moments and Powers: The net muscle joint moments and powers were based on Winter's (1990) definition. Net muscle joint moments can be utilized to determine the extensors' or flexors' dominant at any given time for the joint concern. The polarity of net muscle joint powers indicated that if the muscle group was under concentric or eccentric contraction. The muscular moment pattern generated by the landing leg was similar for all subjects.

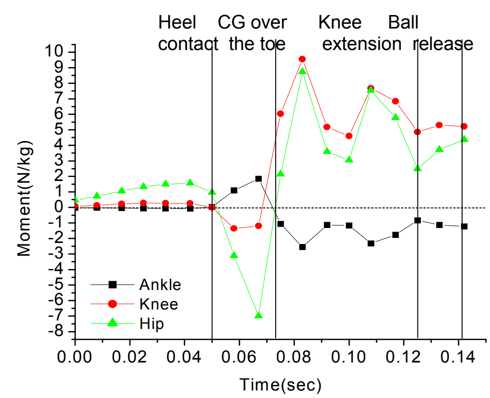

Figure 2 - Net muscle joint moments.

Figure2 and 3 showed the ankle, knee and hip moments and powers curves of one subject's landing leg. From heel contact to ground to CG over the toe, it was shown that ankle and knee flexor contracted concentrically to accelerate the step down action and accelerate rotational velocity of the lower limb and trunk then caused the hip to move forward and drive the CG moving toward the front. During this time the hip extensor was contracted eccentric ally to avoid the hip to stay behind while the body position would affect the direction of releasing ball. After the CG moving to in front of the toe, the ankle and knee contracted eccentrically to avoid the CG to fall (Sprague, 1980), and produced the braking action on lower limb. The hip flexors contracted concentrically to produce forward rotation of upper body and it would bring the pitching shoulder forward and cause the ball path to flat out as it approaching the point of release (Hay, 1993). Before releasing ball the ankle and knee extensor executed concentric contraction to

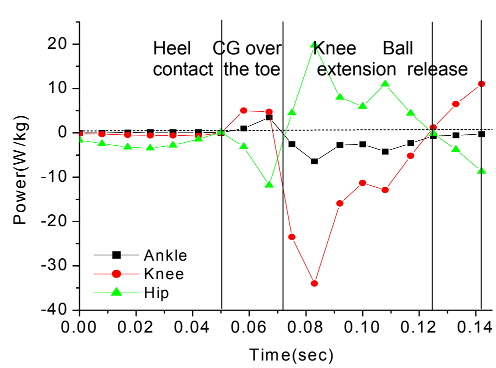

Figure 3 - Net muscle joint powers.

produce extension of landing leg and stop the body rotation to transfer the energy to pitching arm, at the same time the hip executed flexor contraction eccentric to stable the body.

Net Muscle Joint Powers: In the study, the subject with faster velocity of ball at release had lower negative value of the mean powers during the landing phase (Tab.2). The major part of negative powers came from the knee extensor's eccentric contraction, and from the hip flexors' concentric contraction, which produced most of passive powers (Tab.3). The eccentric muscle powers of knee extensor and concentric muscle powers of hip flexor were the important abilities of softball pitching performance.

Table 2 Mean Powers and Ball Release Velocity

Subject	A	B	C	D
Mean Power (W/kg)	-232.09	-144.70	-72.82	-66.30
Velocity of Ball Release (m/s)	23.57	23.92	24.02	24.3

Table 3 Contract Concentrically and Eccentrically Powers of Muscle Group

Muscle Group	Ankle		Knee		Hip	
	Plantar-flexor	Dorsi-flexor	Extensor	Flexor	Extensor	Flexor
Contract Concentrically Power (%)	5.1	0	21.6	11.3	0	62.0
Contract Eccentrically Power (%)	14.7	0	67.3	0	9.7	8.2

This study found the activity in absorbing the shock of landing leg wasn't adequate. Sheu (1999) hypothesized that during the initial landing; the hip flexion and knee extension could reduce the load of ACL and heel tendon. However, during the softball pitching landing, the hips forward flexion and active flex knee joint was inhibited to increase stepping down force. Devita and Skelly (1992) showed that, the ankle plantarflexors provided the major energy absorption function (44% of the total muscular work during the landing) followed by the knee (34%) and hip (22%) extensors. But during the landing of softball pitching, the ankle and hip joint dissipated few impact forces (ankle: 14.7 %; hip: 17.9 %) (Tab3.) due to heel landing and trunk forward rotation technique. Furthermore, this study found that the peak ground reaction forces appeared between 23.3~36.6ms. Nigg (1985) had identified impact forces that occured in less than 50~75ms were passive forces; it implied that the human neuromuscular system didn't produce reaction response to modify these forces. These large passive forces might lead injury to bones, joints and soft tissues (Ricard & Veath, 1990).

Joint Reaction Forces and Stress: The time of the peak joint reaction forces came at peak ground reaction forces during the landing leg contact, with the ankle had the greatest value, following by the knee and hip successively (Fx: Ankle 2.5±0.4BW□Knee 2.4±0.4BW□Hip 2.1±0.3BW□Fy: Ankle -3.8±0.4BW□Knee -3.7±0.5 BW□Hip -3.4±0.5 BW). In addition, the horizontal and vertical joint reaction forces

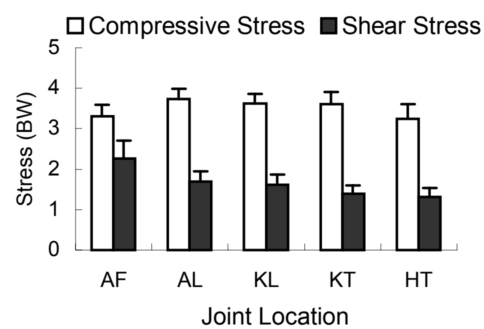

Figure 4 - Peak shear and neutral axis stresses.

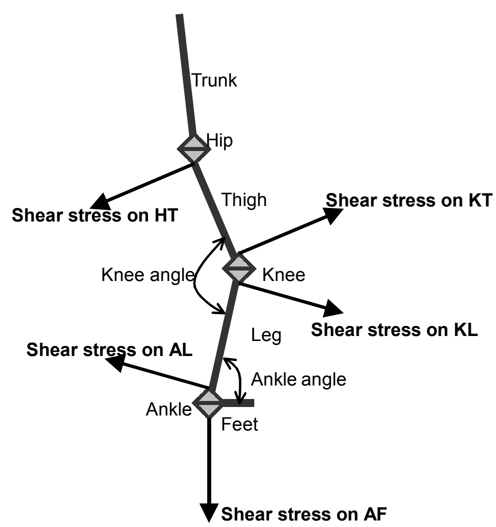

Figure 5 - Directions of shear stresses during landing.

was converted into neutral axis stresses, which parallel to the longitudinal bone and shear stresses which perpendicular to the longitudinal bone (Fig.4). All the neutral axis stresses are compressive stresses (negative value); it could cause the injury at bonds, joints and soft tissues. The directions of shear stresses within ankle are negative (Fig.5) and the ankle was under flexion (average ankle angle=99.3±6.1). This might put the load on the heel tendon. The directions of shear stresses within knee were positive (Fig.5) when knee was under flexion (average knee angle=148.6±0.6). This might increase the load on ligament and muscle tendon. In addition, Furthermore, the directions of shear stresses within leg and thigh were different. This might cause the load at bone.

CONCLUSION: The softball pitcher would encounter hundreds of landing impact during practice sessions and competitions. This study found that the peak ground reaction forces appeared before the human neuromuscular system responded to modify these forces. The greater compressive and shear stress created during the landing phase putting a heavy load on joint soft tissue, ligament and tendon. The repeating greater impact forces during landing action might cause lower extremities injury. It was suggested that important of equipment and shoes would decrease the impact forces and reduce the lower extremities injury during softball pitching.

The result of this study could apply to practical training. The strong ankle, knee and hip muscles would increase stepping down ability, and direct the CG forward and build a good body position in the early part of landing. In addition, the strong eccentric muscle powers of knee extensor and concentric muscle powers of hip flexor were effective energy transference in the pitching arm effectively, which would increase the release ball velocity.

REFERENCES:

Alderson, J., & Elliott, B. (1999). Kinetics of the windmill softball pitch for women. In R. H. Sanders , & B. J. Gibson (Eds.), *Scientific proceedings of the XVII International Symposium on Biomechanics in Sports* (pp.277-280). Perth, Australia□Edith Cowan University.

Devita, P., & Skelly, W. A. (1992). Effect of landing stiffness on joint kinetics and energetics in the lower extremity. *Medicine and Science in Sports and Exercise, 24,* 108-115.

Elliott, J., Grove, R., & Gibson, B. (1988). Timing of the lower limb drive and throwing limb movement in baseball pitching. *Internal Journal of Sport Biomechanics, 4*, 59-67.

Hay, J. G. (1993). *The biomechanics of sports techniques* (4^{nd} ed.). New Jersey□Prentice Hall.

MacWilliams, B. A., Choi, T., Perezous, M. K., Chao, E. Y. S., & McFarland, E. G. (1998). Characteristic ground-reaction forces in baseball pitching. *The American Journal of Sports Medicine, 26*, 66-71.

Mann, R., & Sprague P. (1980). A kinetic analysis of the ground leg during sprint running. *Research Quarterly for Exercise and Sport, 51*(2), 334-348.

Nigg, B. M. (1985). Loads in selected sport activities-An overview. In D. A. Winter, R. W. Norman, R. P. Wells, & K. C. Hayes (Eds.), *Biomechanics □-B* (pp.91-96). Champaign, IL: Human Kinetics.

Ricard, M. D., & Veatch, S. (1990). Comparison of impact forces in high and low impact aerobic dance movements. *International Journal of Sport Biomechanics, 6*, 67-77.

Sheu, T. Y. (1999). Biomechanical analysis of children landing from different highs. Unpublished Master's Thesis. Nation Taiwan Normal University of P.E., Taipei, Taiwan.

Winter, D. A. (1990). *Biomechanics and motor control of human movement* (2^{nd} ed.). New York : John Wiley & Sons.