THREE-DIMENSIONAL DYNAMIC ANALYSIS FOR THE LOWER EXTREMITY DURING FASTBALL BASEBALL PITCH

Tomohisa Miyanishi and Masakata Mukai
Faculty of Physical Education, Sendai College, Miyagi, Japan

Five collegiate baseball pitchers, who have different types of delivery, were videotaped and analyzed using three-dimensional videography and ground reaction force (GRF) anaysis. Just before stride foot contact, a peak vertical GRF of 1.28 BW for pivot foot was produced, resulting from the joint torques for the knee and hip extensors. A peak forward GRF of 0.67 BW also appeared. This GRF may result in the ankle plantar flexors. Immediately after stride foot contact, the joint torques of hip's extension, abduction and internal rotation, knee's extension and valgus, ankle's plantar flexion for the striding leg were generated in order to resist the resultant of vertical and backward GRFs.

KEY WORDS: baseball pitching, lower extremity, joint torque, GRF

INTRODUCTION: In baseball pitching, it is commonly agreed that a high velocity throwing pattern mainly consists of a forward step by the striding leg, pelvic rotation, trunk rotation, shoulder external / internal rotation, elbow extension, forearm pronation and wrist palmar / ulnar flexion of throwing limb. In these sequential movements, it is generally believed among athletes, coaches and researchers that the lower legs play a very important role in order to produce the mechanical energy transfer from the lower limbs to the distal segments of the throwing arm limb and then ball in the final stage of pitching motion. In the past fifteen years, many investigations have been devoted to the three-dimensional (3D) kinematic and/or kinetic study on the baseball throwing (including the pitching) motion using the motion picture camera. However these previous studies have concentrated not on the lower limb, but on the throwing arm itself. Elliott et al (1988) studied the ground reaction force (GRF) of lower limb in order to examine the timing of lower limbs drive and throwing limb movement in baseball pitching. However they did not examine the GRF acting on the stride foot. MacWilliams et al (1998) also investigated the time-course changes for the GRF acting on both feet to clarify the relationships between the GRF and the pitching mechanics. But, they did not consider the joint torques for the lower legs. Thus no joint torque data for the lower legs during the pitching motion could be identified in previous studies. Although the joint torque results from the muscular activity (Andrews, 1982), it often also develops from the external force (e.g. GRF) applied to the body segment. The joint torque analysis will provide a better understanding the mechanisms causing the GRF as well as the specific method of the muscle training for the lower extremity. Therefore the purposes of this study were to obtain information on the joint torque of the lower extremity during a fastball pitch of the baseball by using the inverse dynamics method with two high-speed video cameras and force platforms, and to find the relationships between the torque and the GRF.

METHODS: Five, healthy collegiate male skilled right-handed pitchers (mean height 1.78 m; mean mass 75 kg) participated in this study. In their type of delivery three pitchers had an overhand throw type, the remaining pitchers were a three-quarter throw and a sidehand throw type. Five to ten pitches, with maximum effort, were filmed with two Nac high-speed video cameras (HSV-500C^3) at a nominal rate of 250 fields/s. GRF data (triaxial components, a center of pressure, and a moment about the vertical axis) acting on the pivot and stride feet were recorded at 5000 Hz using two Kistler force platforms (Type 9281CA), in which bult-in the same level ground. A trial pitched with maximum ball speed at the instant of release and judged to be in strike zone by the catcher were selected for kinetic analysis. A Motion Analysis Video System (Frame-DIAS, DKH Inc.) was used to digitize the locations of 25 anatomical body landmarks (vertex, centre of head, suprasternal, distal ends of metacarpal III, wrist joints, elbow joints, shoulder joints, 12th libs, hip joints, knee joints, ankle joints, calcaneums, distal ends of metatarsal II and distal phalanges) and the centre of ball at 4 ms intervals from 80 ms prior to the lack of ground for striding foot to 80 ms after ball release. 3D coordinates of the body landmarks and ball's centre were reconstructed by the direct linear transformation (DLT) method (Abdel-Aziz, & Karara, 1971) expressed in a right-handed orthogonal reference system (Fig. 2). The 3D coordinates were then smoothed by a butterworth low-pass digital filter (a fourth-order, zero-lag filter) as selected by the optimal cutoff frequencies (range: 7.5 Hz-25 Hz) for each coordinate using the residual analysis method (Winter, 1990). The subject's body was modeled as a linkage of 15 segments (head, upper torso, lower torso, upper arms, forearms, hands, thighs, shanks and feet). Inertial properties of all body segments for each subject were estimated by using a previously reported method (Ae et al, 1992). Newton's equations of motion for lower torso, thighs, shanks and feet developed in order to calculate the "resultant" joint torques for the hip, knee and ankle joints for both legs. The joint torques were expressed as triaxial anatomical movements for hip, knee and ankle joints.

RESULTS: Figure 1 shows the stick figures with the various information. Typical time-course GRF changes for the pivot and stride feet are shown in Figure 2. The magnitudes and patterns of GRFs were very similar among the five subjects analyzed in spite of differing of the types of delivery, and also fairly similar to that reported by MacWilliams et al. In pivot foot, vertical (Z) GRF was a change with two peak magnitudes of 1.28±0.15 body weight (BW: at t = 1.42±0.42 s before stride foot contact: SFC) and 1.28±0.14 BW (t = 0.24±0.12 s before SFC), respectively. A minimum vertical GRF of 0.69±0.14 BW was occurred before SFC, at t = 0.68±0.13 s. A peak anterior (Y) GRF of 0.67±0.11 BW was appeared just before SFC, at t = 0.11±0.02 s. In striding foot, vertical and anterior GRFs at ball release (BRL) were 1.51±0.19 BW and 0.69±0.14 BW, respectively. The magnitudes of the right / left (X) GRF for both feet were small, amounting for less than 0.1 BW during the pitching cycle. Typical changes of the joint kinetics for the both legs are shown in Figure 3. In pivot leg, a moderate abduction torque for the hip joint was produced in the early stage of the pitching cycle, and became an adduction torque approximately at the start of the weight shifting phase (Number 4 for stick figure in Fig. 1). The peak extension torques of 113±44 Nm for the hip joint and of 149±33 Nm for the knee joint were reached before SFC, at t = 0.23±0.13 s and t = 0.23±0.07 s, respectively. The peak plantar flexion torque of 114±28 Nm for the ankle joint

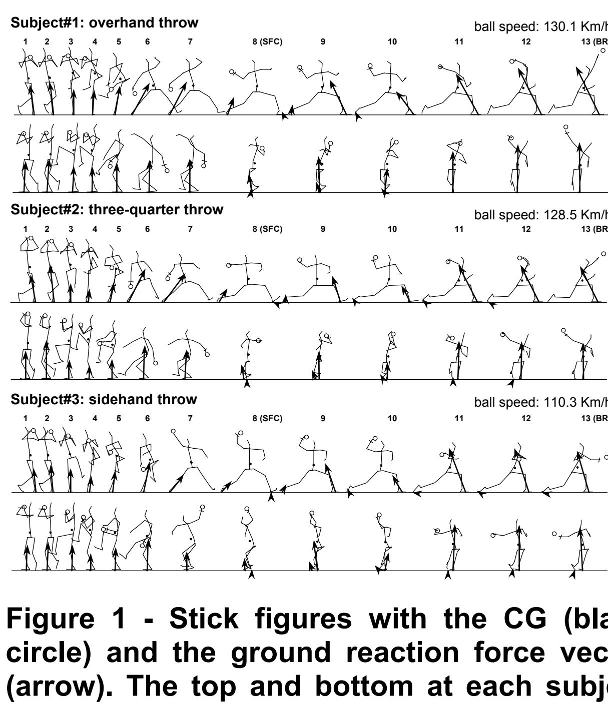

Figure 1 - Stick figures with the CG (black circle) and the ground reaction force vector (arrow). The top and bottom at each subject show a view from the lateral side and anterior one, respectively. SFC and BRL indicate at the instants of the stride foot contact and ball release.

was reached just prior to SFC, at t = 0.12±0.05 s. In the stride leg, the extension torques for the hip and knee joints increased rapidly just after SFC, and its peak values reached just prior to BRL, that is 289±10 Nm at 0.16±0.04 s for the hip joint and 116±29 Nm at 0.15±0.05 s for the knee joint, respectively. The abduction and internal rotation torques for the hip joint, valgus torque for the knee joint, plantar flexion torque for the ankle joint also increased just after SFC (Fig. 3).

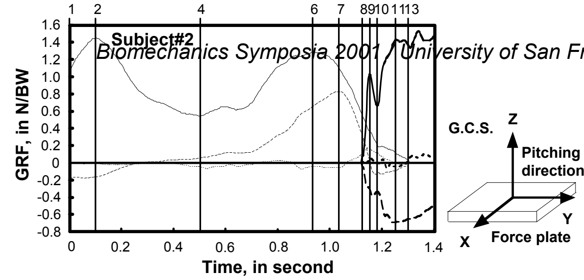

Figure 2- Changes of GRFs acting on the pivot and stride feet in Subject#2. Shin lines with solid, broken and dotted shows the vertical (Z), anterior-posterior (Y) and right-left (X) GRFs for the pivot foot, and also thick lines for the stride foot. Each number for the vertical lines corresponds to that for the stick figures of Subject#2 in Fig. 1. Force data are normalized with body weight (BW).

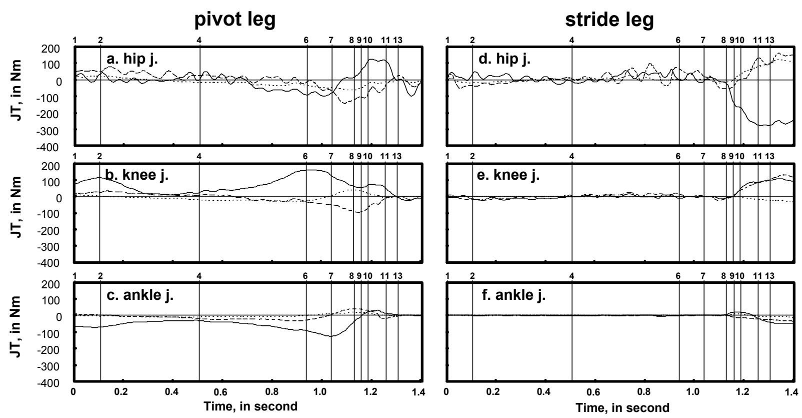

Figure 3 - Changes of joint torque for pivot (left side) and stride (right) legs in Subject#2. Solid, broken and dotted lines indicate flexion(+)/extension(-), abduction(+)/adduction(-) and internal(+)/external(-) rotation for the hip joint; flexion(+)/extension(-), valgus(+)/varus(-) and internal(+)/external(-) rotation for the knee joint; dorsi(+)/plantar(-) flexion, adduction(+)/abduction(-) and pronation(+)/supination(-) for the ankle joint, respectively. See in Fig. 1 and 2 for each number of the vertical lines.

DISCUSSION: GRF data reveal how the pitcher moves toward the home plate. At the maximum striding leg lift (Number 4 for stick figure in Fig. 1), a minimum vertical GRF for pivot foot, in which have an unweighting effect, was produced. After then vertical and anterior GRFs (indicating the downward and backward push-off forces), gradually increased. These downward and backward push-off forces by the pivot leg are shifting the pitcher toward the home plate (Elliott et al, 1988). On the other hand, "breaking force", that is the resultant of vertical and posterior (backward) GRFs produced by landing of the stride foot stopped the lower limbs movement and prohibits the pitcher from moving to the home plate. But, these GRFs play an important role in producing the large joint torques (and/or mechanical energy) for the stride leg, as mentioned in later. In this study, the peak anterior GRF for pivot foot was in 0.67 BW that twice larger than in 0.35 BW reported by MacWilliams et al (1998). There was also an observation of the minimum vertical GRF of 0.69 BW for pivot foot, which did not appeared in data reported by MacWilliams et al. These differences indicate that the subjects in present study used more "drop and drive" technique with pivot foot than in that of MacWilliams et al, representing "tall and fall" technique during the weight transfer phase (House, 1994). Elliott et al

(1988) pointed out that from the first balance position, the pivot leg extended at the hip and knee joints and plantar flexed at the ankle to drive the body forward to the home plate. In their study, however, no joint torque data demonstrated. In this study, the joint torques for the hip, knee and ankle joints at the both legs during the pitching cycle could be identified (Fig. 3). In the pivot leg, the second peak vertical GRF for the pivot foot mainly comes from the knee and hip extensors, because the appearance time for the peak extension torques (both t = 0.23 s before SFC) of the knee and hip joints correspond fairly to that for the second peak vertical GRF (t = 0.24 s before SFC) for the pivot foot. For the same reason, the peak anterior GRF (peak time: t = 0.11 s before SFC) for the pivot foot is derived from the ankle plantar flexion torque (peak time: t = 0.12 s before SFC). In the striding leg, on the other hand, the marked increase of the joint torques which were observed, resulted from resisting to the moment of GRFs about each joint occurred by the stride foot contact. The resultant of vertical and posterior GRFs acts as a flexion moment about the hip joint, indicating rotation of the lower torso forward to the home plate as shown in Fig. 1. At that time, a production of the large hip (also knee) extension torque (Fig. 3) prevent the lower torso from rotating to the home plate. This extension torque also might have a function that produces the mechanical energy in the torso and stride limb segments. Further investigation including energy flow analysis would be necessary.

CONCLUSIONS: The ground reaction forces (GRFs) acting on the pivot and stride feet, and also the joint torques for the both legs during a fastball pitch of the baseball could be identified. In this study, two major findings were concluded: i) the GRFs were limited in two forces, namely anterior (forward) / posterior (backward) and vertical forces. ii) The vertical GRF for the pivot foot mainly results from the knee and hip extension torques for the pivot leg, whereas the forward GRF comes from the ankle plantar flexion torque. In order to resist the resultant of vertical and backward GRFs just after the stride foot contact, the joint torques of hip's extension, abduction and internal rotation, knee's extension and valgus, ankle's plantar flexion for the stride leg were generated. This finding strongly suggest that the pitcher should strengthen the muscles of the lower extremity.

REFERENCES:

Abdel-Aziz, Y.I., & Karara, H.M. (1971). Direct Linear Transformation from Comparator Coordinates into Object Space Coordinates in Close-Range Photogrammetry. In *Proceedings of the Symposium on Close-Range Photogrammetry* (pp.1-19), Falls Church, VA: American Society of Photogrammetry.

Ae, M., Tang, H.P., & Yokoi, T. (1992). Estimation of Inertia Properties of the Body Segments in Japanese Athletes. In SOBIM Japan (Ed.). *Biomechanisms,* 11 (pp.23-33). Tokyo: University of Tokyo Press.

Andrews, J.G. (1982). On the Relationship Between Resultant Joint Torques and Muscular Activity. *Medicine and Science in Sports and Exercise*, 14, 361-367.

Elliott, B, Grove, J.R., & Gibson, B. (1988). Timing of the Lower Limb Drive and Throwing Limb Movement in Baseball Pitching. *International Journal of Sport Biomechanics*, 4, 59-67.

House, T. (1994). The Pitching Edge. Champaign, IL: Human Kinetics.

MacWilliams, B.A., Choi, T., Perezous, M.K., Chao, E.Y.S., & McFarland, E.G. (1998). Characteristic Ground-Reaction Forces in Baseball Pitching. *American Journal of Sports Medicine*, 26, 66-71.

Winter, D.A. (1990). Biomechanics and Motor Control of Human Movement, 2nd ed. New York: John Wiley & Sons.