BIOMECHANICAL ANALYSIS OF THE BASEBALL PITCHING

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ABSTRACT

Many baseball players, especially pitchers, have been injured on their shoulder during pitching motion, because the shoulder is suffering from repeated over-stress. In the late cocking phase the shoulder is externally rotated far beyond the normal range of motion by the inertia force applied on the forearm due to the rapid forward movement of the shoulder. Many researchers have analyzed pitching motion. However no one could calculate the inter-joint force which was loaded between the glenoid fossa and the humeral bone. The purpose of this study was to calculate the joint moment, the muscle force, and the inter-joint force on the shoulder during pitching. The subjects were five elite baseball pitchers. Twenty-four reflective markers were attached to the subjects. Four 60 Hz CCD TV cameras (ExpertVision; Motion Analysis) were used to calculate 3D location of these markers. The ball speeds of these trials were 71 to 87 % of each subject's average speed during real baseball matches. Approximately 54ms prier to the ball release, the shoulder was rotated into external direction rapidly. A large amount of muscle activities was found in the follow through phase. The inter bone-to -bone force in the shoulder joint during the phase was over 7000 N which was nearly 8 times of the player's body weight.

1. INTRODUCTION

Baseball is one of the most popular sports in Japan and in the USA. However, many players especially pitchers, have been injured on their arms. So a scientific approach was started in U.S.A. Tullos (1973) stated the activity of the muscles during the pitching motion and the mechanism of the injuries qualitatively. He mentioned the importance of the worm-up. Jobe et. al. (1983, 1984) measured the myo-graphic records during pitching. Papas (1985a) stated the motion of the scapula and described the diagnostic method and the rehabilitation procedure. He also (1985b) measured the pitching motion with high speed motion cameras, and calculated the angular velocity of the shoulder angle. Gowan (1987) and Glousman (1988) reported the myo-graphic activities, and established the method in this field.

Feltner (1986) calculated the joint moment, which is the sum of the moments of the muscle forces, and the accelerating force on the shoulder and the elbow. That was the beginning of the kinetic-kinematic analysis of the pitching motion. Some Japanese researchers also measured and calculated the angles or joint moment with film analysis or video-based motion analysis systems.

However, we should know about a bone-to-bone force in the shoulder joint during pitching to talk about the mechanism of the injury. Nobody calculated this force. This research is the sample of the method to calculate the bone-to-bone force from motion captured data.

2. METHOD

The subjects were 5 professional baseball pitchers. All were right-handed persons. Twenty-four small reflective markers were fixed on the subject with rubber bands (Fig. 1). All subjects told us that these markers and bands did not disturb their motion. A motion capture system (ExpertVision; Motion Analysis, USA)

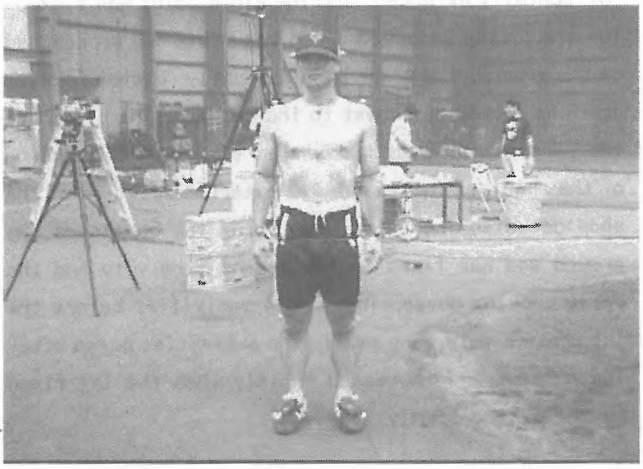

Fig. 1 Markers attached on a subject

with four CCD cameras were equipped in an indoor gymnasium where the players usually use (Fig. 2). There were many ultra-red LED ramps around the lens of the cameras so that the reflective markers were seen as the very bright spots on the CCD cameras. The system scans the bright spots automatically and calculates the 3D location of the markers in 60 frames a second. A software, Eva, which was distributed by the vendor was used to measure the data during pitching. Two digital VCR cameras recorded the motion to check the procedure.

Fig. 2 Measurement system

Data were brought to a lab, and Eva software calculated the 3D locations of the markers. When Eva confused marker ID, identification of the marker was necessary on the user interactive bases. Fig. 3 shows a personal computer monitor display which shows the play-backed motion of the subject as a stick diagram. 3D location of the markers was output on the Ascii text file. The file was converted to a DIFF (Data InterFace File). The DIFF data was fed into another software, which was coded by ourselves, to calculate the center of the joint, angles of the shoulder and the elbow, joint moments, muscle contraction forces, and joint bone-to bone forces. The procedure will be explained briefly bellow.

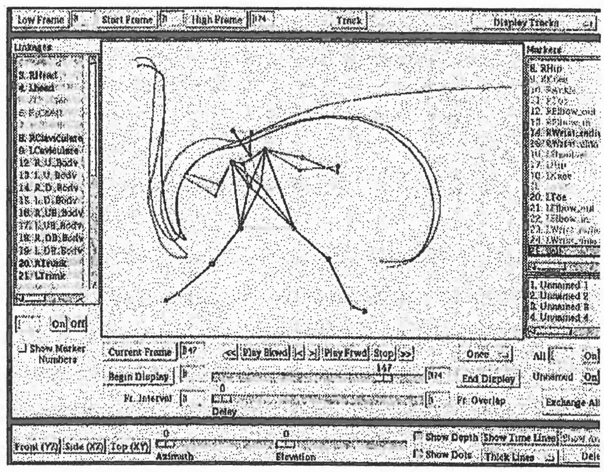

Fig.3 Reconstructed stick diagram data on a dsiplay

At first, the center of the shoulder joint, the elbow joint, and the hand were calculated from the geometrical arrangement of the markers. The shoulder angles and the elbow angle were calculated from these data. And Eular angles of the upper arm and forearm were calculated, which will be required to calculate the joint moment. The gravity and the total sum of the moment of the muscle forces give the motion of the body segment. So, the total sum of the muscle moments, which is called the joint moment, can be calculated from the motion data of the body segment, provided the gravity on each segment is known. The gravity can be estimated by the segment angle and the estimated segment mass. In this way the joint moment on the shoulder joint and the elbow joint were calculated from the motion captured data.

The joint moment is the sum of the moment of many contributing muscles to the joint. In our model, 16 muscles are contributing to the shoulder, and 5 muscles for the elbow joint. If we know the degree of the

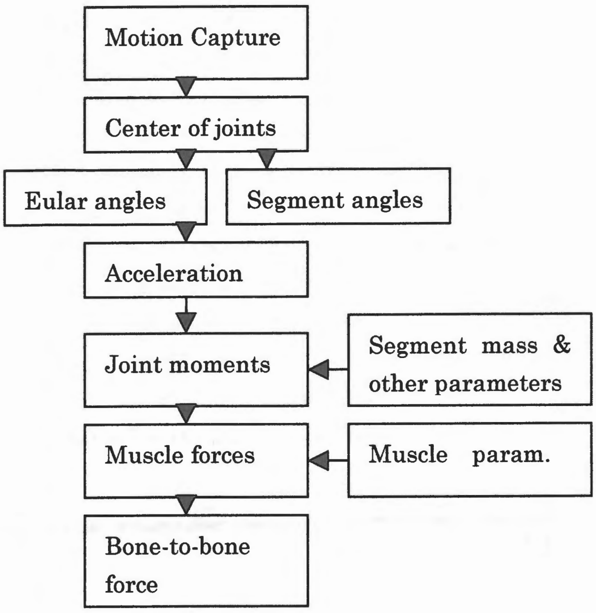

Fig. 4 Calculation proceedure

contribution of each muscle, we can estimate the muscle forces from the joint moment. We estimated the muscle forces by utilizing the assumption in which the sum of the squares of the muscle forces divided by its maximum contraction force might be minimized. This assumption was derived from the more basic assumption in which humans activate the muscles in the manner they minimize the fatigue of the muscles.

The bone-to-bone force is produced mainly by the muscle forces contributing the motion of the adjacent segments. So, finally, bone-to-bone force in the shoulder was calculated from the muscle forces around the shoulder joint.

3. ANALYSIS AND RESULTS

In this report, pitching motion was divided into 5 phases. These are: winding up, early cocking, late cocking, acceleration, and follow through.

The data was analyzed as follows.

In the winding up phase the player shifted his body weight on his supporting leg after he prepared the initiation. He lifted his swing leg. The body was falling toward the home plate because of the gravity. The variation of the form in this phase largely depends on the player. Velocity of the body motion was small, and the muscle activities were also small. So any possible causes of an injury were not found in this phase. This phase ended when the ball left the grove.

In the early cocking, the upper body kept its direction to the right. Hip joints were abducted side way, that was toward the catcher to prepare the ground contact. The body kept falling. The shoulder was abducted and horizontally extended, and the elbow joint was flexed. The arm lifted backward. When the swing leg approached to the ground, the trunk was vertically rotated forward as if he showed his chest to the catcher. The elbow and the forearm remained backward so horizontal extension of the shoulder increased. The external rotation of the shoulder also increased. The swing leg contacted the ground and was fixed to the ground firmly to end the early cocking phase. The muscle activities before the leg contact were very small. The activities began after leg contact and increased rapidly when the leg fixed to the ground firmly.

In the late cocking phase, vertical rotation of the trunk kept increased. The trunk shifted forward and the swung right-arm remained backward. So, the external rotation and the horizontal extension of the shoulder increased more and more. Finally the external rotation reached to its maximum angle. That is the end of the late cocking phase. The average maximum external rotations of our subjects was 55 degree which was a little bit smaller than Papas' (1985b) result (70 deg.). The maximum external rotation during pitching was 50 degree far beyond the usual normal range. So, a lot of stress on this instance was suggested. During this phase the activities of the coracobrachialis, the

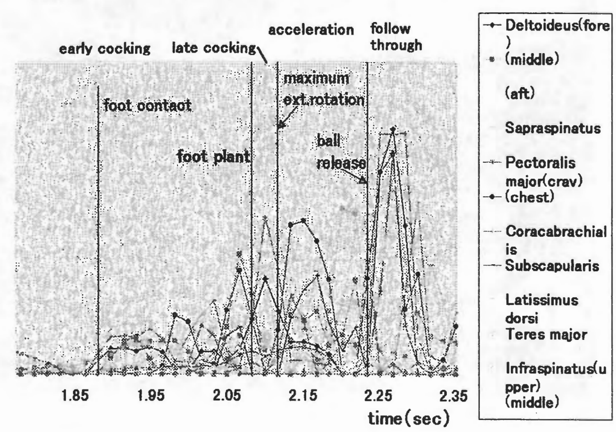

Fig.5 Estimated muscle force during pitching

supraspinatus, and front part of the deltoideus were high. As already mentioned the external rotation and the horizontal extension were increased in this phase, but this was not because of the muscle activities. It was because of the inertial force on the arm.

After the maximum external rotation the acceleration phase began. The shoulder angle changed its direction to internal rotation, horizontal adduction, and adduction. The movement of the horizontal adduction stopped at the very instance of the ball release because of the reaction of the internal rotation to make forearm rotate forward. The ball was released at the end of the acceleration phase. The ball speeds which were calculated from the data were from 101 to 125 km/h. Those were from 71 to 87 % of the ball speeds during a real match for each subject. So, our data were

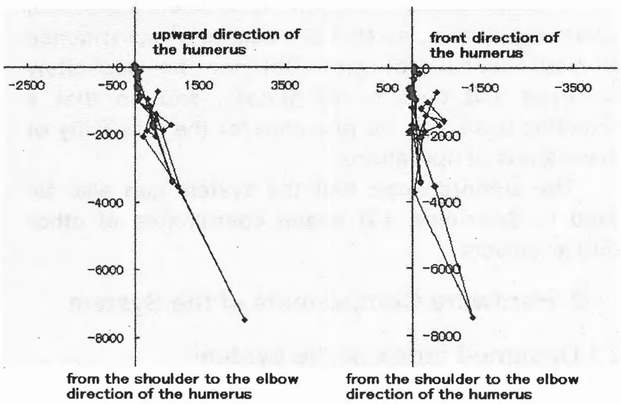

Fig.6 calculated bone-to-bone force in the shoulder

considered to be close to the situation of a real match. The average duration of the late cocking and the acceleration were 73 and 54 ms. These were similar value to the Papas' (1985b). In this acceleration phase the muscle activities increased very much. Especially the pectoralis major, the brachialis, and the latissimus dorsi showed the activity around 800 N.

After the ball release, that was the follow through phase. Very large muscle activities were found. So, it was thought that muscle activities were required to make the body segment stop its movement. The supraspinatus, the deltoideus, the coracobrachialis, the andpectoralis major enlarged its activities more than before the ball release. Peak force of the supraspinatus reached to 1500 N. Corresponding to the large muscle activities during the follow through phase, the force produced in the shoulder reached to 5000 N. The direction of the force was approximately along the upper arm. This bone-to-bone force was nearly 6 times of the body weight.

4. CONCLUTION

We applied the motion capture technique to a rehabilitation purpose. We could estimate the bone-to-bone force in a joint with motion captured data. In this method we could get into inside of our body without touching. The information obtained in this research will contribute the rehabilitation procedure of baseball players. The needs for this new method will increase in the future.

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