Introduction

Spontaneous fractures of the humeral shaft have been reported due to throwing objects such as grenades, handballs, softballs, and baseballs (Branch et al., 1992; Ogawa et al., 1998; Reed et al., 1998; Hennigan et al., 1999). Although thankfully not a common injury, these catastrophic fractures have been noted in the medical literature for over two hundred years, and have occurred in several high-profile professional baseball pitchers. The resulting fractures are generally spiral in nature, suggesting they arise from torsion of the humerus about its long axis (Ogawa et al., 1998). Because these fractures occur during the throwing motion, the forces acting on the upper extremity during the throw are a likely cause. However, it is not clear which aspects of the throwing motion cause the fracture, or when during the motion they occur. The large shoulder and elbow forces generated during the pitching motion have been well documented (Fleisig et al., 1996; Werner et al., 1993). However, the relationship between pitching biomechanics and torsional stress acting on the humerus has not been studied. The aims of the current study were to provide an explanation of the mechanism of humeral shaft fractures and to identify the phase of the pitching motion during which they are most likely to occur.

Methods

Two high-speed video cameras were used to videotape 40 professional pitchers competing in preseason games at a frequency 120 Hz from front and dominant side views. The locations of 21 body landmarks were digitized manually and the three-dimensional locations of each of the points were calculated using the DLT method (Abdel-Aziz et al., 1971). From the three-dimensional coordinates, the kinematics of the pitching elbow and shoulder were calculated throughout the pitching motion. Definitions of the elbow and shoulder angles used in this study are shown in Figure 1.

Joint kinetics at the shoulder and elbow were computed using an inverse dynamics approach. The arm was modeled as a series of four rigid links, interconnected by ball-and-socket joints. Segment mass and inertia parameters were taken from the literature (Whitsett, 1963; Clauser et al., 1969), and scaled to the height and mass of the subject using the technique described by Hinrichs (1990). Joint resultant forces and torques were calculated for each joint in the inertial reference frame. Local segment-based
reference frames were established at the shoulder and elbow joints. The joint resultant forces and torques were projected onto each of these reference frames to provide anatomical relevance. Internal forces and torques acting along or about anterior-posterior (A-P), medial-lateral (M-L), and distal-proximal (D-P) axes were computed using a standard technique (Feltner et al., 1986; Dillman et al., 1993). Internal forces and torques represent the joint forces and torques applied by the more proximal segment at the joint onto the proximal end of the more distal segment at that joint.

The net humeral forces and torques were calculated as the difference between values at the proximal and distal ends of the bone, expressed in the local humeral coordinate system. These net humeral forces and torques were assumed to indicate the state of stress applied to the humerus at any given time. The net humeral axial torque (about the D-P axis of the humerus) tends to twist the humerus about its shaft. When this value is positive, the proximal end of the humerus is being rotated externally relative to the distal end (Figure 2). We hypothesized humeral torque is related to incidence of humeral shaft fracture since it results in torsional stress likely to result in spiral fracture of the shaft a long bone.

Kinetic data was normalized in time to facilitate comparisons among players and so mean values could be calculated. The pitching motion was considered to start at stride foot contact (0%) and end shortly after ball release (90%). Data from the fastest pitch thrown for a strike by 25 professional pitchers were analyzed. This subgroup of pitchers was selected due to their similar pitched ball speeds.

**Results & Discussion**

The mean age of the subjects was 26.8±2.9 years, and the mean pitch speed was 38.8±2.0 m/s (range 36.2 to 44.3 m/s). Maximum external rotation angle (MER) of the shoulder averaged 182±13° (Figure 3, top). This represents a combination of glenohumeral and scapulothoracic motions, as well as trunk hyperextension (Fleisig et al., 1996). The largest net force acting on the humerus was an axial force causing tension in the humerus (Fig. 3, middle). This force was largest in magnitude (about -2000 N) just prior to ball release when the shoulder internal rotation velocity was near its maximum. The largest net torque about the humerus was a twisting torque about the shaft of the humerus, which reached a value of nearly –200 Nm about 80% through the pitch (Fig. 3, bottom). Since the sign of this torque is negative, it tended to rotate the proximal end of the humerus internally relative to the distal end and peaked immediately prior to MER.

The forces and torques acting on the humerus agree with the mechanics of the pitching motion, and also with the proposed mechanism of humeral shaft fracture. An internal rotation torque at the shoulder exists prior to MER, while the humerus and forearm are still externally rotating. The internal rotators, especially subscapularis, pectoralis major, and latissimus dorsi, are applying an internal rotation torque at the proximal end of the humerus at that instant (Glousman et al., 1998; Gowan et al., 1987). At the distal end of the humerus, the forearm and hand are creating an external rotation torque on the humerus, evidenced by the large varus torque required at the elbow at the same instant. The result is a net external rotation torque acting about the long axis of the humerus (distal end of humerus externally rotated more than proximal end). The humeral torque generated near the time of MER in the pitching motion is likely
related to the pitcher’s risk of suffering a humeral shaft fracture. Such fractures are generally spiral in nature, and are consistent with shear failure of the bone due to the application of a large torsional stress. Therefore, fractures are most likely to occur just prior to MER, when the humeral torque is greatest. The direction of the torque acting on the humerus is consistent with the appearance of external rotation spiral fractures noted by Ogawa et al. (1998) in their series of 90 patients. Pitching style seems to affect humeral torque, since values varied widely even among our group of pitchers with similar pitch speeds.

Our findings show that during the cocking phase of the pitch there is a net external rotation torque acting about the shaft of the humerus. This net torque is consistent with the mechanism of humeral shaft fracture during a pitch. The data also suggest that fractures occur at or near the time of MER when net humeral torque peaks, and not after release as some authors have suggested (Ireland et al., 1995). Further research is needed to verify the relationship between humeral torque and likelihood of humeral shaft fracture.

References