Biomechanical analysis of the mechanism of elbow fracture-dislocations by compression force

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Abstract Fracture-dislocations of the coronoid and olecranon were produced experimentally, and their onset mechanisms were analyzed to clarify the effects of compression force on the coronoid and olecranon. The study used two-dimensional finite element method (2D-FEM) simulations and static loading experiments. The latter applied axial force distally to 40 cadaveric elbows. Posterior fracture-dislocations occurred between 15° of extension and 30° of flexion, anterior or posterior fracture-dislocations at 60°, and only anterior fracture-dislocations at 90°. Injuries were mainly to anterior or posterior support structures. The 2D-FEM simulations showed that the stress concentration areas moved from the coronoid process to the olecranon as position changed from extension to flexion. The very high frequency of concurrent fracture-dislocations of radial head or neck in the current study indicated that the radial head may also function as a stabilizer in the anterior support system.

Key words Fracture · Fracture-dislocation · Elbow · Biomechanics

Introduction

The articular surfaces of the distal humerus, proximal ulna, and radius form three subsidiary joints within the elbow. Among them, the humero-ulnar joint plays the most important role in stabilization of the elbow. The elbow joint is also supported by soft tissues, including joint capsule, ligaments, and muscles. With failure of these supporting systems, the elbow joint may dislocate. Failure of a particular support subsystem results in characteristic fracture-dislocation patterns, which are classified according to the joint area: anterior, posterior, medial, and lateral. The recognition of fracture mechanisms and types is important for treatment planning. To clarify the effects of compression force on the coronoid and olecranon in coronoid and olecranon fracture-dislocations, fracture-dislocations of the elbow joint were experimentally induced and their onset mechanisms were analyzed. The onset mechanisms of these fractures were also analyzed using a two-dimensional finite element method (2D-FEM).

Materials and methods

Fracture experiments using cadaveric elbows

Fifty-three intact elbows were selected arbitrarily from 46 cadavers (50–95 years of age at death, mean age of 78.2 years; 28 males, 18 females; 27 right and 26 left elbows) for systematic dissection. Pre- and posttest radiographs of the 53 cadaveric elbows were taken. In the experimental fracture-dislocation study, 40 of the 53 elbows preserved with 10% formalin were used. The humerus was cut transversely 90 mm proximally to the distal joint surface. The radius and ulna were transected evenly at a point either 60 mm (short ulna model) or 90 mm (long ulna model) distally to the coronoid tip.

The humerus, radius, and ulna with elbow joint cartilage and the surrounding joint capsule and ligament were left intact in the short and long ulna experimental models. The humerus, radius, and ulna were fixed in dental resin to a depth of 30 mm in the specimen holders of the loading apparatus (Fig. 1). The elbow joint was positioned at 15° of extension and 0°, 30°, 60°, or 90° of flexion in a custom-made specimen holder, and loads were applied with a Shimazu Autograph S-2000 (Shimazu, Tokyo, Japan) (Fig. 2). The axial force was applied at 10 mm/min in the direction of the long axis of the humerus to produce fracture-dislocation. Ten of the 53 elbows were used in the varus or valgus stress tests and were fixed at 0° of elbow flexion in full supina-
tion position of the forearm. Angles were checked with a goniometer before each loading test.

Three additional right elbows were used in the coronoid resection model. The anterior capsule was excised to gain access for removal of varying amounts of the coronoid incrementally after each experiment (one-third, one-half, and two-thirds) after the radius was removed.\(^4,19\) The longitudinal axis of the ulna with a Kirschner wire (K-wire) inserted into line AB was marked for pretest radiographs (Fig. 3). Line DE was marked with a K-wire. Point P represented the furthest point on the coronoid process from line AB. Line PC was drawn perpendicular to line AB. Line PC was divided into thirds or halves by cut lines drawn perpendicular to line AC; K-wires were inserted on a selected cut line through the greater sigmoid notch. Accuracy of the cut line was verified radiographically before cutting. The coronoid process was then cut along that line and all wires were removed. The elbows in this model were extended gradually from the position of flexion under axial pressure, and the angle on dislocation was measured.

**Finite element study**

The lateral radiograph of a normal elbow of a 32-year-old male volunteer was mapped in two-dimensional coordinates and made into two versions of 2D-FEM (Fig. 4).

Stress distribution in the elbow joint model was analyzed in several positions within the normal range of movement. The results from the FEM analyses were compared with those of the experimentally produced fractures to verify changes in location of areas of stress concentration and fracture sites at the tested elbow joint angles.

The model was divided into four areas according to the different properties of four materials: cortical bone,