INTRODUCTION:
The elbow is the second most common joint that is dislocated. Fortynine percent of these are complex dislocations (i.e. associated with a fracture). There are classic patterns for elbow injuries. Previous experiments have attempted to recreate these injury patterns using external forces. Elbow dislocations and fracture-dislocations are most frequently described as being caused by an axial force accompanied by flexion and an additional varus, valgus, or rotation force that leads to posterior dislocation with injury to either the medial or lateral structures. Classically, it is believed that the elbow must be flexed 20 degrees to unlock the olecranon before a dislocation can occur. The hypothesis of this study was that elbow fracture dislocations can occur with the elbow in full extension, and that patterns of injuries are influenced both by forearm orientation and interaction of joint surfaces in compression of the extended elbow. Therefore, the objective of this study was to investigate the joint kinematics and injury pattern when an axial load is applied to failure in extension with different forearm orientations.

METHODS:
Fifteen upper extremities were resected through the distal 1/3 of the humerus. Soft tissues were removed, leaving only the joint capsule, ligaments, intersosseous membrane, and muscular insertions of the brachialis, supinator, and triceps. The valgus angles of the specimens were determined using markers and digital photos in supination, pronation, and neutral. A custom apparatus was built to allow free rotation of the ulna, radius, and humerus about a fixed wrist. A compressive load was applied with a material tester (Instron 4411, Canton MA) at a rate of 2 mm/second until failure occurred. Force and displacement were measured. An optoelectronic, three-dimensional camera system (Optotrak 3020, Northern Digital Inc., Canada) was used to measure kinematic data for the distal humerus, proximal radius, and proximal ulna. Following failure, the elbow was also carefully inspected and photographed to document all fractures and disrupted tissues.

RESULTS:
Of the fifteen specimens, seven elbows failed in pronation and seven elbows failed in supination. One specimen did not fail despite reaching a load of 4-kN, which was the upper limitation of the material tester. Six of the 7 elbows loaded in pronation had a fracture of the radial head and coronoid with posterior dislocation. One specimen tested in pronation had both a bone fracture of the forearm before elbow failure. Six of the seven elbows loaded in supination dislocated without coronoid or radial head fractures. One of the seven elbows tested in supination had a terrible triad type elbow injury with radial head fracture, coronoid fracture, and posterior dislocation. Four of fourteen elbows had damage to the lateral structures and 10 of fourteen had injury to the medial structures. In each case, damage to either the medial or lateral structures correlated with internal or external rotation of the ulna as compared to the humerus.

Load to failure of the extended elbow in pronation lead most commonly to a terrible triad (fracture of radial head and coronoid with posterior dislocation). Allowing independent rotation of the ulna and humerus enabled the elbow to dislocate in full extension in the supinated position. There was not a fracture of the radial head or coronoid. No additional forces were necessary to allow the ulna to rotate out of the olecranon fossa. Post failure dissection revealed injury to either the medial or lateral structures. The documented structural injuries correlated with the calculated rotations of the humerus and ulna relative to each other. When the ulna had a greater external rotation relative to the humerus, the lateral structures were damaged. When the ulna had a greater internal rotation, there was damage to the medial structures. The post failure dissection demonstrated rotation laxity at the elbow after reduction.

DISCUSSION:
Clinical scenarios and elbow injuries captured on video suggest that the elbow could dislocate without the elbow flexing. We set out to determine if elbow dislocations or fracture dislocations could occur with the elbow in full extension. In our previous study we established a physiologic system to apply an axial load with the humerus, radius, and ulna able to rotate independently around a fixed wrist. This mimics the most common clinical situation. In the current study, the elbows were loaded to failure. Interestingly, the classic injury patterns occurred without flexing the elbow. Post failure dissection revealed injury to either the medial or lateral structures. The documented structural injuries correlated with the later calculated rotations of the humerus and ulna relative to each other. When the ulna had a greater external rotation relative to the humerus, the lateral structures were damaged in a pattern similar to that described by O’Driscoll et al.1 When the ulna had a greater internal rotation, there was damage to the medial structures consistent with the clinical injury patterns as described by Josefsson et al.2 The reason for internal rotation of the ulna on the humerus versus external rotation is not clear. Perhaps the intrinsic joint surface geometry causes the ulna to hinge either medially or laterally and allow the elbow to dislocate. The ligaments of the contralateral side are torn or attenuated. The post failure dissection demonstrated rotation laxity at the elbow after reduction.

One reason for the previous belief that flexion is necessary for an elbow dislocation to occur is prior studies have been unable to create a dislocation in full extension without a fracture of the radial head, olecranon, or coronoid. If the ulna is not allowed to rotate out of the olecranon fossa, a fracture would be necessary to allow the dislocation. Another interesting finding in this study was the occurrence of the classic terrible triad injury pattern in pronation. Six of the seven elbows loaded in pronation had this injury pattern. This cadaveric model will be useful for future studies investigating the repair of these structures.

REFERENCES:

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