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Experimental Investigation of Posterior Elbow Dislocation in a Primate Model

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Abstract—The purpose of this experimental study was to define the soft and bony tissues changes as the elbow joint dislocates posteriorly in a primate model. Sixty-six fresh arms were used in this study and were divided into two groups where manual and automated procedures were performed to address the mechanism of elbow dislocation. The first group called IA (50 arms) was tested using a special designed apparatus and was used for Instron machine whereas second group IB (16 arms) a manual dislocation by hyper-extending the elbow at the end of the tabletop was performed. An axial compressive load was applied on the distal forearm at a constant rate of 10 mm/min in group IA. The humerus was rigidly secured on a humeral plate at 90 degrees (3), 45 degrees (17), 30 degrees (13) and 0 degrees (17) of elbow flexion. Photographs and computer data recorded the changes in the soft tissue and bone at the elbow. It required on average 1960 N to dislocate the elbow in pronation with flexion (45, 30 degrees) compared to 1030 N for supination and the elbow flexion (45, 30 degrees). Three reproducible stages of dislocation from initiation to complete failure were observed when the elbow was flexed at 45 degrees or 30 degrees with forearm pronated or supinated.

I. INTRODUCTION

THE elbow-joint is defined as a ginglymus or hinge-joint and it is supported by soft tissues, including joint capsule, ligaments and muscles. The main ligaments in the elbow-joint are lateral collateral ligament (LCL), medial collateral ligament (MCL) and radial collateral ligament (RCL). Any failure in the support system may results in different pattern of elbow dislocation classified according to joint area: anterior, posterior, medial, and lateral. The most common mechanism of traumatic posterior elbow dislocation (80% of all dislocations) is a fall on an outstretched hand with axial loading of the flexed elbow and forearm pronated. Hildenbrand et al reports that the annual incidence of elbow dislocations is 6-8 cases per 100,000 population[1]; these dislocations represent 11-28% of all injuries to the elbow. About 30% of elbow fractures in adults occur in the radial head. Olecranon process fractures account for 20% of all elbow injuries in adults. Coronoid process fractures occur in 10-15% of dislocations of the elbow. Hyperextension force at the elbow with forearm supinated is another known mechanism. Combined hyperextension and supination have been claimed as the cause of lateral epicondylitis if the pain is localised laterally[2]. It was reported according to an epidemiological study[3] that 75% of soccer goal keepers experience elbow problems through their career in which 95% sustained pain through hyperextension of the elbow when blocking a shot[4]. Reconstructing falling is one of the most challenging problems in biomechanics. Current models which attempt to reconstruct falls usually focus on inverse dynamics[5] where muscles forces are determined mathematically. O'Driscoll et al. hypothesized that the elbow can dislocate posteriorly with a functionally intact anterior medical collateral ligament (AMCL) [6]. O'Driscoll assumed that the mechanism of dislocation during a fall on the outstretched hand would involve the body rotating internally on the elbow, which experiences an external rotation and valgus moment as it flexes. Dislocation occurs at 80 degrees of flexion with posterior lateral rotation of 34 to 50 degrees and 5 to 23 degrees of valgus moment. He also suggested that posterior dislocation can be reduced in supination. In another study, Wake et al. reported that posterior fracture-dislocations occurred between 15 degrees of extension and 30 degrees of flexion[7]. Cohen et al. suggested that the disruption of the ulnar part of the lateral collateral ligament contributed to the poster lateral instability of the elbow [8]. The goal of this present study is to design a new experiment in which posterior elbow dislocation is investigated and its stages of dislocation are outlined and analyzed. This experiment was used to validate our hypothesis that during a fall the elbow will dislocate posteriorly with soft tissue disruption from lateral to the medial side. We also believe that the radial head may function as a stabilizer in elbow dislocation. The procedure and methods allowed for determination of the maximum load needed to initiate dislocation and describe how the ligamentous lesion is induced.

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II. PROCEDURE

A. Material and Methods

Sixty-six fresh arms were used in this study and were divided into two groups where manual and automated procedures were performed to address the mechanism of elbow dislocation. In the first group called IA (50 arms) was tested using a specially designed apparatus and loaded using an Instron machine whereas second group IB (16 arms) a manual dislocation by hyper- extending the elbow at the end of the tabletop was performed. All sixty six arms were thawed and dissected of all non ligamentous soft tissues. In dissection the subcutaneous layers, skin and muscles of the baboon arm were taken off. The lateral collateral ligament, medial collateral ligament and the radial collateral ligament were left intact along with the joint capsule (Fig 1). In addition three baboon arms and one human arm were dissected to compare the anatomic structure of both models. The entire animals used were sacrificed as a part of other experimental investigation. The primate cadaver upper extremities were harvested from studies that were approved by the Institutional Animal Care and Use Committee (IACUC). All elbow specimens were from a female baboon and the average age at sacrifice was 15 years. Specimens were kept at -20 degrees Centigrade to preserve ligament properties. The humerus was disarticulated from the shoulder joint as well as the radius and the ulna was disarticulated from the wrist. The humerus was rigidly secured on an inclinable humerus plate at 90 degrees (3), 45 degrees (17), 30 degrees (13) and 0 degrees (17) of elbow flexion. The distal end of the radius and the ulna were cemented in a metallic cup after being oriented in supination or pronation. An axial compressive load was applied to the metal cup at constant rate of 10mm/min till the elbow dislocates (Fig 2) in Group IA. Video camera was placed posteriorly to the elbow joint and kept in focus to capture stages of dislocation. Video files were digitized and correlated with data files (force & displacement) taken from the Instron machine 5569. Photographs and computer data recorded the changes in the soft tissue and bone at the elbow joint. In Group IA, the distal end of the radius and ulna were oriented in 90º pronation (25 arms) and in 85º supination (25 arms). The humerus was completely fixed before orienting the ulna and radius in 90º pronation or in 85º supination. To examine the sequence of rupture the ligament were identified by coloring them such as Pink, Orange, and Green for AMCL, PMCL, and LCL, respectively. The radial head and coronoid fractures where categorized by either Type I or Type II Fx fractures. The maximum load that initiated dislocation was measured for the 50 specimens. The apparatus consists of three main parts: adjustable humerus, adjustable forearm holder and metal cup (Fig 2). The inclinable top plate could be used to adjust different angle of flexion and extension. An adjustable ring was designed to accommodate different sizes of ulna and radius. A metal cup holder was designed to give a smooth translation. A swiveling bar was used to give different angle of flexion. Sliding rings could slide and position with respect to the elbow. The jig was designed in “Pro engineer Software” and then manufactured at medical instrument shop (Fig 3).

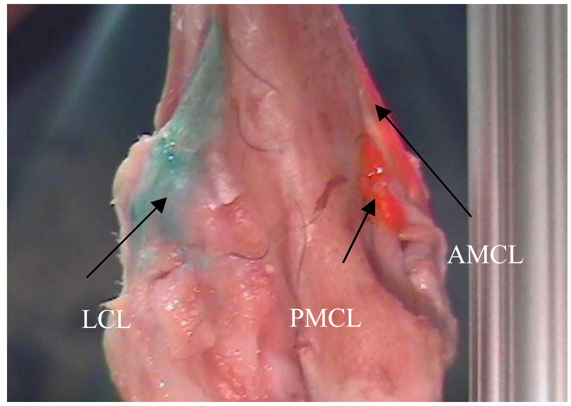


Fig. 1. Posterior View of the AMCL,LCL,PMCL

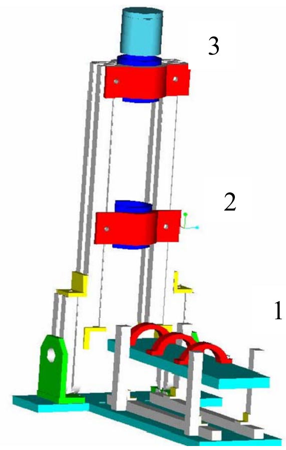


Fig. 2. Testing apparatus. 1-Adjustable humerus, 2-Adjustable Forearm holder, 3- Metal cup**.**

III. PRELIMANARY RESULTS

A. Mechanism of Elbow Dislocation

The loading experiments produced various dislocations and certain sequence of ligaments rupture. It was not possible to dislocate the elbow joint with the elbow flexed at 90º and forearm pronated (1 arm) or supinated (2 arms). Instead the humerus fractured in each instance. In Group IA, the forearm being pronated and elbows at 45º (6 arms) and 30º (9 arms) of flexion showed an average load of 1960 N (Fig 4.). At that load a pop sound was heard in all of the fifteen experiments. This pop sound was due to either radial head or coronoid fracture or possibly both at the same time. Sequences of ligaments rupture were monitored. It was observed that the anterior medial collateral ligament peels off last in 12 of the 15 baboon elbows and remains attached in the other three elbows. Posterior medial collateral ligament was first to rupture in 14 elbows and second only once. The lateral collateral ligament ruptured first in one elbow, second in 12 elbows and remained attached in two elbows .Only one trial resulted in having the AMCL and LCL rupturing together at the same time. An average load of 1030 N resulted in fracture elbow dislocation in group IA with the forearm supinated and elbows at 45º (11 arms), and 30º (4 arms) of flexion (Fig 4.). Elbow dislocation started with an anterior edge fracture of the radial head followed by tip fracture of the coronoid process. The same procedure was followed in group IA with the supination group where sequences of ligaments rupture were monitored .The experimental results showed the anterior medial ligament (AMCL) was last to peel off in 11 arms. The posterior medial ligament was first to rupture in the 15 arms. Lateral collateral ligament was left attached in 4 arms and ruptured second in sequence in 11 arms. Two experimental setups resulted in having the AMCL and the LCL rupturing together at the same time.

Posterior elbow dislocation was also produced by applying a hyperextension load with humerus fixed at 0º of flexion .The average load was 488 N in 9 arms (90º Pronation) and 8 arms (85º Supination).

Fig. 3. Axial loading Apparatus

Elbow Flexion	Forearm Pronation	Supination	Newtons
45º or 30º	Yes		1960*
45º or 30º		Yes	1030*
0º		Yes	488*
90º	Yes	Yes	Unable to dislocate
* P< 0.001			

Fig. 4. Average Load needed to reproduce elbow dislocation.

B. Stages of Dislocation

Three reproducible stages of dislocation were observed when the elbow was flexed at 45º or 30º with the forearm pronated or supinated. These stages were defined from a common pattern seen in these experiments. Stage I can be characterized as a bony failure stage where fractures of the anterior radial head and or coronoid process occurred (Fig 5a). It is believed that fractures occur at about the same time possibly starting with coroniod process (Type I or II Fx). In this stage posterior lateral displacement of the radius and ulna with stretching of capsule and ligaments was observed. Stage II, radial annular ligament tears followed by posterior lateral capsule tear (Fig. 5a.). Stage III, sequential tearing of the radial collateral ligament (Fig. 5b.) followed by medial collateral ligament (Fig. 5c.), anterior capsule and rest of posterior capsule were observed (Fig. 5d.).

In the specimens subjected to a hyperextension force only, three reproducible stages were noted. Stage I: Detachment of the anterior capsule. Stage II: Rupture first of the anterior ulnar ligament followed by tearing of the posterior ulnar collateral ligament (occasionally the radial collateral ligament tore first. Stage III: Anterior elbow dislocation with or without rupture of the lateral collateral ligament.

C. Radial Head and Coronoid Fractures

Experimental results show frequent fracture of the radial head and the coronoid process during elbow dislocation. In group IA, with the elbow flexed at 45º and in 85º supination or 90º pronation there was 100 percent and 76 percent fracture of the coronoid process and anterior radial head as the elbow dislocates. Fractures of the radial head (65 percent) and respectively coronoid process (54 percent) occurred with the elbow held at 30º of flexion When both 45º and the 30º group were combined there was 76 percent chance of breaking either the ulna coronoid process or the radial head. In the hyperextension elbow group no axial loading was used and no fractures noted.

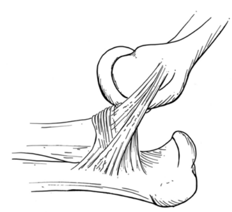


Fig. 5a.

Fig. 5b.

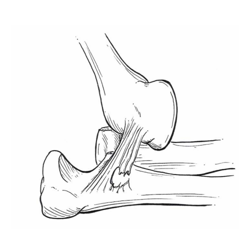


Fig. 5c.

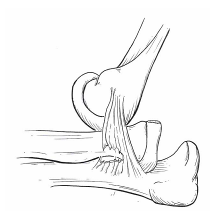
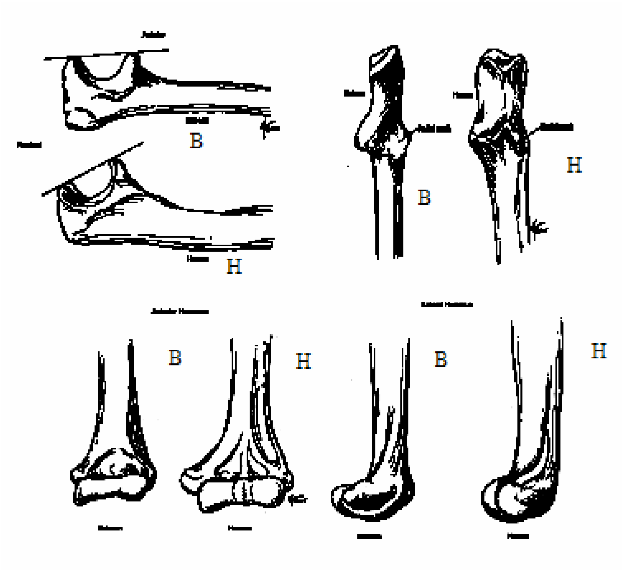


Fig. 5d.

D. Comparative Anatomical study

Comparative anatomical study was conducted on the similarity between baboon elbow joint and human elbow joint. Results shows that bony and soft structure of the baboon closely resembles those of the human (Fig. 6.) with some exceptions. The trochlea notch of the ulna is oriented 25 degrees posteriorly compared to 0 degrees in the baboon. Baboon elbow usually extends up to minus 10 degrees. The baboon ulnar radial notch is relatively larger and it is more.

The coronoid and radial fossae of the baboon are shallower. The baboon capitellum is less spherical.



Fig, 6. The bony and soft structure of the baboon versus those of the human. B. Baboon. H. Human

IV. DISCUSSION

Our study uses a baboon model to reproduce posterior elbow dislocation. We tested both mechanisms in the primate model and made the following important observations. 1. Bony failures in the form of the radial head and or ulnar coronoid process fracture were the first important event before there was soft tissue tearing with axial loading of the flexed elbow in either supination or pronation. This bony failure stage was common in group IA among arms tested in which we can conclude that the radial head is acting as a stabilizer during dislocation. Significantly less force was needed to dislocate the flexed elbow in supination than in pronation. 2. Soft tissue failure occurred first in the absence of bony fracture with hyperextension force to the elbow in the absence of axial loading. 3. Fifty percent to 60 percent less force was needed to dislocate the elbow occurred with direct posterior hyperextension force. 4. The lateral soft tissue structures and lateral posterior capsule were the first to fail with elbow flexion group whereas the anterior capsule followed by the medial ligament structures were the initial tissue to fail with forced hyperextension. 5. The baboon (Papio Anubis) is an excellent animal model to study elbow function since the elbow anatomy and range of motion are mostly similar to humans in addition to being more cost effective than human cadavers. 6. Results also show the common pattern in ligament sequence of rupture starts with posterior medial collateral rupture followed by lateral collateral rupture followed by anterior medial collateral ligament peeling. In this experiment we are able to prove our hypothesis that the mechanism for posterior elbow dislocation is defined as the initiation of the radial head, ulna and coronoid fracture followed by anterior tearing of the joint capsule, lateral collateral ligament rupture, posterior medial collateral ligament rupture and medial collateral ligament peeling off the ulna. The clinical significance of this comprehensive study supports the observation that most low impact posterior elbow dislocations in the earlier stages are sufficiently stable in most cases to be treated by closed reduction and early mobilization since by all mechanism sufficient bony or soft tissue stability is retained. The advanced stages of an elbow dislocation are expected to have significant medial and lateral collateral ligament damage.

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