Development of an Animal Model of Post-traumatic Stiffness and Joint Contracture of the Elbow

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Disclosures:

Introduction: Traumatic elbow injuries are a challenging clinical problem, resulting in pain, joint stiffness/contracture, and arthrosis [1-3]. While both extrinsic and intrinsic factors have been reported as contributors [1], the etiology of post-traumatic elbow stiffness remains poorly understood. Previous research on elbow stiffness has focused on human cadaver studies or analysis of surgical biopsies [4, 5], which are limited to “end-stage” analysis of affected tissues. Animal models of joint contracture using rabbit or rat knees have provided information on the biological changes that occur in the capsular tissue of a stiff joint [6, 7], however these models have limited applicability in investigating questions of clinical relevance specific to the elbow. A relevant, validated model is urgently needed to describe the temporal progression of elbow injuries and guide the development of improved treatment strategies. Therefore, the purpose of this study was to develop an animal model of elbow contracture and arthrosis and evaluate its potential for studying the etiology of post-traumatic joint stiffness.

Methods: Species selection. A number of animal species were examined for similarities to human elbows in: (1) functional use, (2) osseous and articulating anatomy, and (3) ligaments and capsule tissue. Functional evaluation considered pronation-supination as well as flexion-extension motion and whether animals had prehensile use of their forelimbs. Anatomically, limbs were assessed for separate ulna and radius bones, three distinct joint articulations, and the presence and accessibility of principal ligaments and capsule tissue in the elbow. Besides sharing many anatomical similarities to humans, rats exhibit extensive use of the forelimb during normal activity. In particular, the Long-Evans breed exhibits functional similarities, including significant pronation-supination and similar joint kinematics during reaching. Surgical Procedure. Ten Long-Evans rats (285±11g) were divided into three groups: Surgery I (n=3), Surgery II (n=3) and control (n=4). Under sterile conditions, the lateral elbow was exposed and an anterior capsulotomy was performed (Surgery I) or an anterior capsulotomy combined with transection of the lateral collateral ligament (LCL) was performed (Surgery II). Contralateral limbs served as an uninjured comparison. After skin closure, operated elbows were immobilized by wrapping the limb in a flexed position using tubular elastic net dressings and Vetrap bandaging. Post-operatively, all rats were allowed regular cage activity for six weeks. During this period, animals were observed daily and fresh bandages were applied 2-3X/week to immobilized limbs. Sample preparation and testing. In order to quantify biomechanical changes, a custom test system was built to cyclically load rat elbows in flexion and extension. Displacement applied by a linear actuator (TestResources, Shakopee, MN) is converted to rotational motion using a rack and pinion gear. Force is measured with a six-degree-of-freedom sensor, which allows for load-controlled testing of the rat elbow. Following sacrifice, forelimbs were removed and skin dissected (Fig.1A). Prior to mechanical testing, bilateral forelimbs were scanned using μ-CT imaging (VivaCT 40, Scanco Medical, Switzerland), and 3D reconstructions were compared between operated, contralateral and control limbs for any differences in bony surfaces, joint spacing or osteophyte formation. Following μ-CT imaging, the proximal humerus and distal ulna/radius were potted in test fixtures and placed in a relaxation position in the mechanical test system. Cyclic loading to ±0.75-N (corresponding to ±0.01125-Nm of torque) was applied for five cycles. Force and displacement data from the fifth cycle were converted to torque and angular position, and the resulting loading curves were analyzed for total range-of-motion (ROM) and neutral zone stiffness (Knz) using a custom Matlab code (Fig.1B) [8].

Results: From the 3D μ-CT reconstructions, no differences were observed between groups in terms of lateral epicondyle surface or humeral-ulnar spacing, which are locations most likely to be affected by a damaged anterior capsule or transected LCL. In addition, no osteophytes were observed. Mechanical test results show a dramatic difference in the shapes of torque-angle curves for injured limbs compared to their contralateral (uninjured) limbs (Fig.1B), with the operated/immobilized limbs exhibiting altered joint motion. Quantitatively, injured limbs demonstrated larger Knz values (Fig.1C) and smaller ROM values (Fig.1D) than their contralateral limbs. While not statistically evaluated because of limited sample numbers, results appear to show no differences between unoperated control and contralateral limbs. However, the average Knz and ROM values were approximately 3X larger and 2X smaller, respectively, for injured/immobilized limbs compared to control groups.

Discussion: Altered biomechanical parameter values demonstrate stiffer (i.e., increased Knz) and more contracted (i.e., decreased ROM) elbow joints as a result of the induced surgical injury and immobilization. The protocol developed in this study caused these quantitative changes to joint mechanics, even though the immobilized joints were only constrained (on average) ~68% of the six-week period as the limb wrapping technique was being refined. Significant improvements to the wrapping protocol were achieved throughout the study, so future investigations with more consistent joint immobilization may lead to even greater mechanical consequences as a result of injury and immobilization. While ROM was slightly lower for Surgery I
animals than the more severe Surgery II animals, these results may be a reflection of differences in relative success of the immobilization wrapping protocol rather than differences in injury severity. Interestingly, no qualitative changes to bony anatomy were observed to accompany the biomechanical results, suggesting that soft tissue alterations may be primarily responsible. Currently, we are quantitatively analyzing the 3D radiological reconstructions to determine if any internal osseous changes occurred (e.g., thickening of the subchondral bone, altered total bone volume), and are performing histological analysis to identify biological changes to the ligament complexes and capsule tissue as a result of this protocol. In this study, an animal model of the elbow was developed using two surgical procedures and joint immobilization, which led to biomechanical changes representative of contracture and stiffness. Future work will evaluate whether these induced changes are temporary or if they persist following remobilization of the affected limb.

Significance: Post-traumatic elbow stiffness and joint contracture are common clinical problems and can occur following substantial injuries or even after relatively minor trauma. The development of a clinically relevant animal model of the elbow will enable the examination of the etiology of these debilitating conditions and help guide the development of improved treatment strategies.

Acknowledgments: The authors acknowledge Daniel Leib and the Washington University Musculoskeletal Research Center (NIH P30 AR057235).
