J Shoulder Elbow Surg (2016) ■■, ■■–■■

JOURNAL OF SHOULDER AND ELBOW SURGERY

www.elsevier.com/locate/ymse

ORIGINAL ARTICLE

Optimizing the rehabilitation of elbow lateral collateral ligament injuries: a biomechanical study

Ranita H.K. Manocha, MD, MSc[a,b], Jonathan R. Kusins, MESc[a], James A. Johnson, PhD, PEng[a,c], Graham J.W. King, MD, MSc[a,d,*]

[a]*Roth-McFarlane Hand & Upper Limb Centre, St. Joseph's Health Care, London, ON, Canada*
[b]*Department of Physical Medicine & Rehabilitation, Western University, London, ON, Canada*
[c]*Department of Mechanical and Materials Engineering, Western University, London, ON, Canada*
[d]*Division of Orthopaedic Surgery, Department of Surgery, Western University, London, ON, Canada*

Background: Elbow lateral collateral ligament (LCL) injury may arise after trauma or lateral surgical approaches. The optimal method of rehabilitating the LCL-insufficient elbow is unclear. Therapists often prescribe active motion exercises with the forearm pronated. Recently, overhead exercises have become popular as they may enable gravity to compress the elbow joint, improving stability, although this has not been proved biomechanically. This investigation aimed to quantify the effects of several variables used in LCL injury rehabilitation on elbow stability.
Methods: Seven cadaveric specimens were tested in a custom elbow motion simulator in 3 arm positions (overhead, dependent, and varus) and 2 forearm positions (pronation and supination) during passive and simulated active elbow extension. Three injury patterns were studied (intact, LCL injury, and LCL with common extensor origin injury). An electromagnetic tracking device measured ulnohumeral kinematics.
Results: Following combined LCL and common extensor origin injury, overhead positioning enhanced elbow stability relative to the other arm positions ($P < .01$ in pronation; $P = .04$ in supination). Active motion stabilized the LCL-deficient elbow in the dependent ($P = .02$) and varus ($P < .01$) positions. Pronation improved stability in the overhead ($P = .05$), dependent ($P = .06$), and varus ($P < .01$) positions.
Conclusions: Rehabilitation with the arm overhead improves elbow stability after LCL injury. Initiating earlier range of motion in this "safe position" might decrease elbow stiffness and allow optimal ligament healing. If exercises are done in the dependent position, active motion with forearm pronation should be encouraged. Varus arm positioning should be avoided.
Level of evidence: Basic Science Study; Kinesiology

Keywords: Elbow; lateral collateral ligament; instability; rehabilitation; range of motion; kinematics; overhead motion protocol; in vitro testing

Acute injury to the elbow lateral collateral ligament (LCL) may occur after trauma, such as a fall onto an outstretched hand, sports injury, or motor vehicle accident, causing elbow subluxation, dislocation, or fracture-dislocation.[31,36] The common extensor origin (CEO) is injured in 66% of acute

Institutional Review Board approval was not required for this study per the University of Western Ontario Institutional Review Board.

*Reprint requests: Graham J.W. King, MD, MSc, Roth-McFarlane Hand & Upper Limb Centre, St. Joseph's Health Care, Room D0-202, 268 Grosvenor Street, London, ON, Canada N6A 4L6.

E-mail address: gking@uwo.ca (G.J.W. King).

1058-2746/$ - see front matter © 2016 Journal of Shoulder and Elbow Surgery Board of Trustees. All rights reserved.
http://dx.doi.org/10.1016/j.jse.2016.09.038

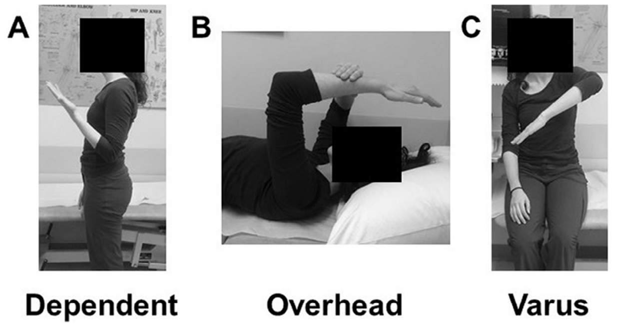

Figure 1 Gravity-loaded arm positions. The arm can be positioned in the gravity-loaded dependent (**A**), overhead (**B**), or varus (**C**) position. The arm is typically in the dependent and varus positions during activities of daily living. Following lateral collateral ligament injury, the patient may keep the arm in the dependent position at rest, may rehabilitate the arm in the overhead position, and will try to avoid the varus position, in which the weight of the forearm and hand results in a destabilizing moment at the elbow.

traumatic LCL injuries,[24] and involvement of this structure is more likely to cause persistent instability as the CEO is an important secondary stabilizer of the elbow.[3,24] LCL insufficiency can also be caused by lateral surgical approaches to the elbow, such as during radial head or coronoid fracture repair or lateral epicondylitis débridement.[28]

Most acute post-traumatic LCL tears without associated fractures are managed nonoperatively.[13,22,35,37] Rehabilitation protocols generally begin with immobilization and motion restriction, followed by gradual progression of passive, active assisted, and active range of motion (ROM).[35,37] Passive ROM involves a patient moving a joint with the other arm or a therapist moving a joint with no assistance from the patient. Active ROM involves a patient actively contracting the muscles to move a given joint. Rehabilitation later progresses to strengthening and, ultimately, sport-, job-, or other function-specific activities.[33,37] The LCL helps prevent external rotatory subluxation of the ulna relative to the humerus and stabilizes the elbow against varus loads.[16,23,27] Thus, positioning the arm in the gravity-loaded varus position (Fig. 1, *C*) is typically avoided in the first 6 to 12 weeks after LCL injuries to avoid putting tensile stresses on lateral elbow structures.[35]

Elbow kinematics in the setting of LCL insufficiency have previously been analyzed with the arm in a dependent (Fig. 1, *A*) position. In this position, instability observed with passive flexion was reduced with simulated (ie, custom motion simulator controlled) active elbow flexion.[5] Forearm pronation has also previously been shown to improve the stability of the LCL-deficient elbow during active and passive flexion with the arm in the dependent position.[5] Whereas passive motion of the LCL-deficient elbow has been studied with the arm in the varus position,[5] the effect of active motion with this condition has not.

It has also been suggested that LCL injuries should be rehabilitated with the arm in a gravity-loaded overhead position (Fig. 1, *B*) as this is thought to enable gravity and activation of the brachialis, biceps brachii, and triceps brachii muscles to cause joint compression and increased congruency and thus improve stability.[35,37] Lee et al have published the only study to date quantifying elbow kinematics with the arm in the overhead position.[21] Using fluoroscopic analysis to evaluate ulnohumeral distance in cadaveric specimens with sectioned LCLs undergoing passive ROM with the forearm in neutral rotation, they found 104% more displacement with the arm in a dependent position compared with an overhead position and concluded that rehabilitation in an overhead position was safe, whereas loading in a dependent position risked dislocation. Although the overhead position is increasingly used in rehabilitation, no biomechanical studies have assessed the effectiveness of simulated active motion in this position.

The purpose of this investigation was to quantify elbow stability during simulated rehabilitation exercises with the arm in the overhead, dependent, and varus positions before and after LCL injury with and without concomitant injury to the CEO and lateral elbow capsule. It was hypothesized that after LCL injury, (1) rehabilitation with the arm overhead would minimize elbow instability compared with the dependent and varus positions, (2) active motion would reduce instability compared with passive motion, and (3) forearm pronation would reduce instability compared with supination.

Materials and methods

Seven fresh frozen cadaveric left upper extremities (mean age ± standard deviation, 76 ± 10 years; 2 male) amputated at the forequarter level were scanned using computed tomography to rule out pre-existing arthritis or fracture. Specimens were stored at −20°C and thawed at room temperature (22°C ± 2°C) for 18 hours before testing and mounted in a custom elbow motion simulator that has been previously described[4,8,12] (Fig. 2). The distal tendons of the biceps brachii, brachialis, brachioradialis, pronator teres, and triceps brachii were individually sutured with running locking braided Dacron (Gamefish Technologies, Newport Beach, CA, USA). The distal tendons of the wrist flexors (flexor carpi radialis and flexor carpi ulnaris) were sutured together, and the wrist extensors (extensor carpi radialis longus and extensor carpi ulnaris) were then sutured together. Sutures were then passed subcutaneously within their respective physiologic compartments to maintain anatomic lines of action of the tendons. In addition, alignment guides were placed at the medial epicondyle for the pronator teres and wrist flexors, at the lateral epicondyle for the wrist extensors, and at the supracondylar ridge for brachioradialis. A custom-machined stainless steel intramedullary rod was inserted into the humeral shaft through the humeral head and cemented with methyl methacrylate. The rod with the largest diameter that could safely be inserted into the medullary canal of the humerus was used (8-mm rod used in 3 specimens, 10-mm rod used in 4). This rod was then rigidly mounted into a custom clamp on the base of the elbow motion simulator. All sutures were then individually connected by stainless steel cables to 3 computer-controlled servomotors (for each of biceps brachii, brachialis, and triceps brachii) and 4 pneumatic actuators (for the remaining tendons).