Journal of Hand Therapy 32 (2019) 80–85

Contents lists available at ScienceDirect

Journal of Hand Therapy

journal homepage: www.jhandtherapy.org

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Scientific/Clinical Article

Efficacy of a radial-based thumb metacarpophalangeal-stabilizing orthosis for protecting the thumb metacarpophalangeal joint ulnar collateral ligament

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ARTICLE INFO

Article history:
Received 20 November 2016
Received in revised form
31 May 2017
Accepted 11 June 2017
Available online 12 July 2017

Keywords:
Orthosis
Thumb ulnar collateral ligament
Thumb ulnar collateral ligament repair
Thumb ulnar collateral ligament injury prevention

ABSTRACT

Study Design: Basic research (biomechanics).
Introduction: The high degree of motion that occurs at the thumb metacarpophalangeal (MCP) joint must be taken into account when immobilizing a partially torn or repaired thumb ulnar collateral ligament.
Purpose of the Study: To determine the efficacy of a radial-based thumb MCP-stabilizing orthosis in resisting abduction across the thumb ulnar collateral ligament.
Methods: Ten fresh cadaveric hands were mounted to a custom board. An anteroposterior radiograph of the thumb was obtained with a 2 N preload valgus force applied to the thumb, and the angle between the Kirschner wires was measured as a baseline. Subsequently, 20, 40, 60, 80, and 100 N valgus forces were applied 15 mm distal to the MCP joint. Anteroposterior radiographs of the thumb were obtained after each force was applied. The angle of displacement between the wires was measured and compared with the baseline angle. The angles were measured with an imaging processing tool. A custom radial-based thumb MCP-stabilizing orthosis was fashioned for each cadaveric thumb by a certified hand therapist. The aforementioned loading protocol was then repeated.
Results: The radial-based thumb MCP-stabilizing orthosis significantly reduced mean abduction angles at each applied load.
Discussion: We found that our orthosis, despite being hand-based and leaving the thumb IP and CMC joints free, significantly reduced mean abduction angles at each applied load.
Conclusions: This investigation provides objective evidence that our radial-based thumb MCP-stabilizing orthosis effectively reduces the degree of abduction that occurs at the thumb MCP joint up to at least 100 N.
Level of Evidence: n/a (cadaveric).

Introduction

An incidence of 50 thumb ulnar collateral ligament (UCL) injuries per 100,000 thumbs per year has been reported.[1] Thumb UCL injuries account for 86% of all traumatic injuries that occur at the base of the thumb.[2] In 1955, Campbell[3] coined the term gamekeeper's thumb when he attributed the attritional wear of the thumb UCL to the repetitive valgus loading of the thumb metacarpophalangeal (MCP) that occurs during the execution of wounded rabbits. Another term used to describe an acute thumb UCL injury is skier's thumb because skiers have been found to be at an increased risk for sustaining this injury during falls.[2] More recently, acute thumb UCL injuries have been more generally associated with a hyperabduction force to the thumb MCP that occurs in athletes.[4–12]

Persistent thumb MCP instability resulting from an UCL injury results in decreased pinch strength and pain and leads to degenerative arthritis.[4,13] Partial injuries are often diagnosed with a firm endpoint on valgus stress testing and can often be successfully

Conflict of interest: All named authors hereby declare that they have no conflicts of interest to disclose.
This research was supported by the National Institutes of Health; P20-GM104937 (COBRE Bio-engineering Core).
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http://dx.doi.org/10.1016/j.jht.2017.06.002

managed nonoperatively, with approximately 4 weeks of immobilization in a thumb spica cast or orthosis, followed by a course of hand therapy.[2] In contrast, complete UCL injuries are best managed with surgical repair and postoperative immobilization because conservative management often results in persistent thumb pain.[1]

Surgical repair of acute complete thumb UCL injuries within 3-4 weeks after injury has been associated with excellent functional outcomes.[2,7,13] However, the repaired ligament lacks the strength of native tissue until the ligament is healed. A thumb UCL repaired with 1 suture anchor has been demonstrated to be significantly weaker compared with the intact UCL.[14] Therefore, UCL repairs are often protected, with full return to activity avoided until adequate ligament to bone healing, which occurs at approximately 10-12 weeks.[2,15] A recent investigation of a 2-anchor thumb UCL repair reported that players returned to football between 4 and 7 weeks after surgery without an orthosis.[4] If adequately immobilized in a cast or orthosis, patients could potentially return to play immediately. However, skill position players, including wide receivers and quarterback in football, often cannot return with the thumb immobilized. At our institution, we allow these skill position players to return to sport at 6 weeks with a radial-based thumb MCP-stabilizing orthosis (Fig. 1).

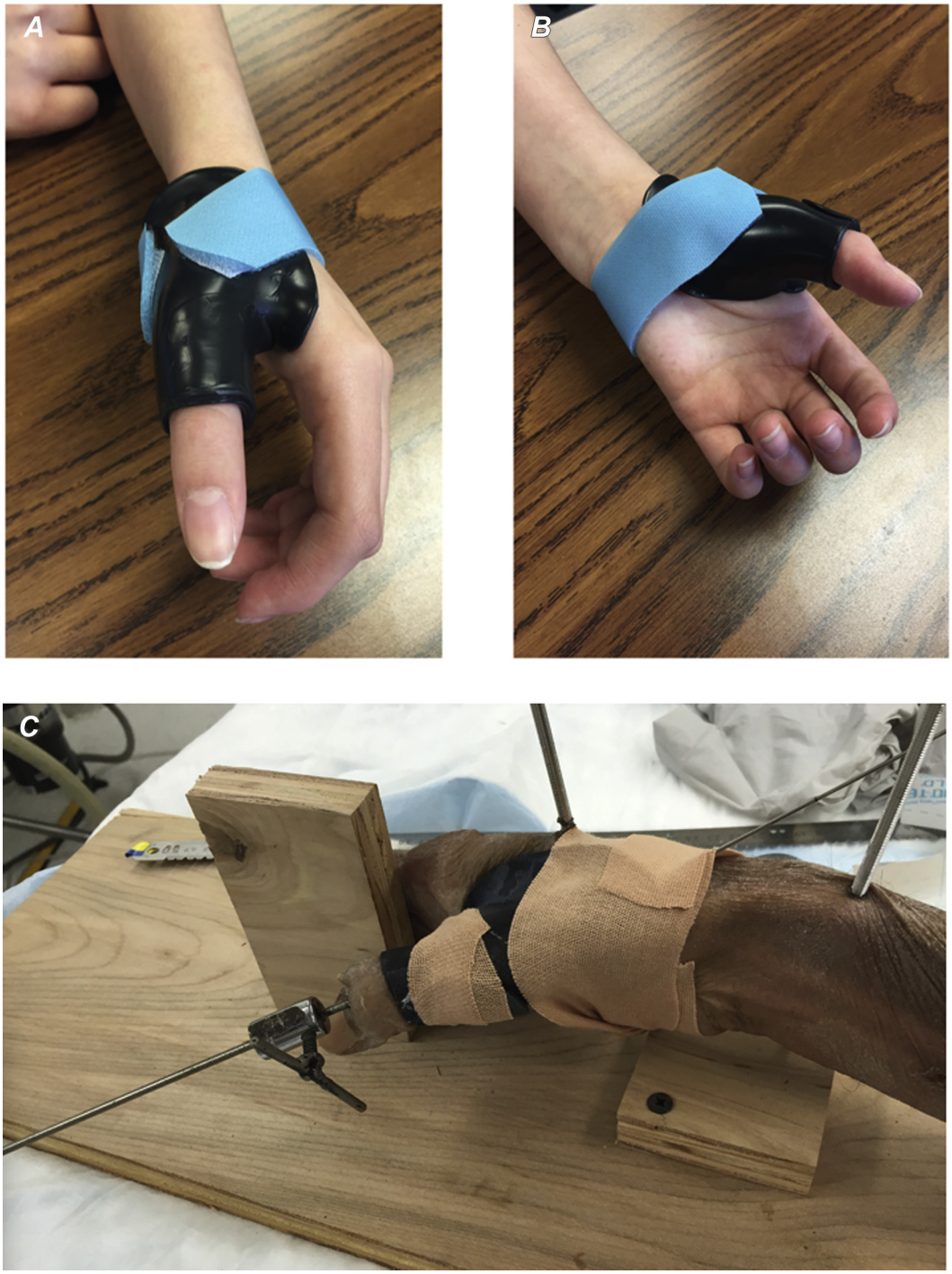

Fig. 1. (**A**, **B**) Clinical photographs of the tested radial-based thumb metacarpophalangeal-stabilizing orthosis. (**C**) Photograph of the orthosis applied to cadaveric hand.

The thumb MCP joint is a combined condyloid and ginglymus joint that allows flexion and extension, ulnar and radial deviation, and rotation.[16] The high degree of motion that occurs at this joint must be taken into account when immobilizing a partially torn or repaired thumb UCL. Low-profile orthoses have been popularized by evidence that demonstrates that allowing the thumb interphalangeal (IP) joint to remain free decreases the risk of extensor pollicus longus adhesion formation and promotes early ligament healing.[17,18] The orthosis is custom made to each patient. The orthosis immobilized the MCP joint, whereas leaving the IP joint and thumb carpometacarpal (CMC) joint free, thereby preserving motion at these joints. In theory, the orthosis protects the repaired thumb UCL while preserving a degree of hand function. Previous investigations have examined the efficacy of thumb UCL immobilization with a forearm-based thumb UCL orthosis.[19] However, no similar investigation has been performed to determine if using a radial-based thumb MCP-stabilizing orthosis compromises the ability of the orthosis to reduce thumb UCL strain with valgus forces applied to the thumb. Accordingly, the purpose of our study was to determine the efficacy of a radial-based thumb MCP-stabilizing orthosis in resisting abduction across the thumb UCL and protecting it from reinjury.

Material and methods

Ten fresh cadaveric hands (3 females, 7 males; average age, 52.6 ± 14.9 years) were frozen and stored in a freezer at −40°F. The specimens were thawed to room temperature, and the hands were harvested at the level of the proximal one-third of the forearm. An anteroposterior (AP) radiograph of the thumb was obtained to exclude cadaveric thumbs with pre-existing arthritis.

The cadaver thumbs were prepared for testing by implanting a threaded 0.062 mm Kirschner wire (K-wire) into the proximal phalanx of the thumb. After flexing the IP joint to uncover the head of the proximal phalanx, the K-wire was percutaneously inserted from distal to proximal along its longitudinal axis. The K-wire was advanced until the K-wire just engaged, but did not breach, the base of the proximal phalanx and left the distal aspect protruding from the first phalanx. A second 0.045 K-wire was implanted into the thumb metacarpal for reference. A wire driver was used to advance this K-wire percutaneously into the thumb metacarpal along its longitudinal axis from proximal to distal. The K-wire was advanced to the level of the metacarpal head taking care not to breach the cortex (Fig. 2).

Fig. 2. The cadaver thumbs were prepared for testing by implanting a threaded 0.062 mm Kirschner wire (K-wire) into the proximal phalanx of the thumb (P1). A second 0.045 K-wire was implanted into the thumb metacarpal for reference.

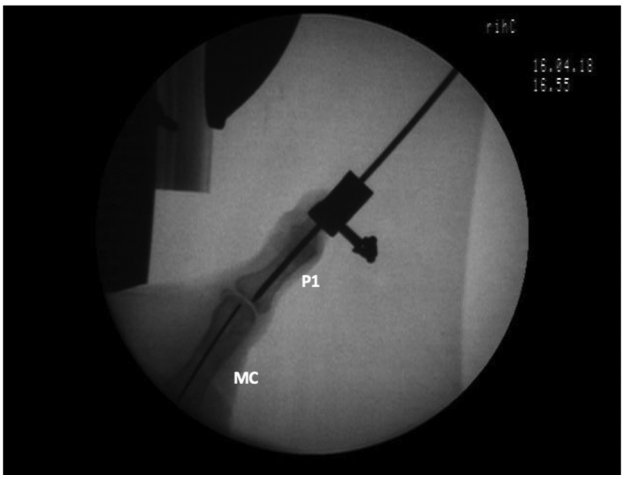

Fig. 3. The distal radius and ulna were mounted to a custom board. The dorsal surface of the thumb MCP was parallel to the board. The metacarpal heads of the index, middle, ring, and small fingers were positioned such that they were stabilized while a load was applied to the thumb. A hook was mounted to the K-wire protruding from the distal end of the proximal phalanx 15 mm away from the thumb MCP joint to ensure that each load applied to the thumb generated consistent torque. MCP = metacarpophalangeal.

The distal radius and ulna were mounted to a custom board (Fig. 3). The hand was positioned such that the dorsal surface of the thumb MCP was parallel to the board. The metacarpal heads of the index, middle, ring, and small fingers were positioned such that they were stabilized while a load was applied to the thumb. A hook was mounted to the K-wire protruding from the distal end of the proximal phalanx 15 mm away from the thumb MCP joint to ensure that each load applied to the thumb generated consistent torque. Loads were applied to the MCP by attaching weights to a cable hanging over a pulley. By placing a block underneath the K-wire protruding from the distal end of the proximal phalanx, the MCP was forced to abduct in 1 plane of motion.

After preloading the thumb UCL with a static 100 N force for 1 minute to eliminate inherent ligament laxity, the 100 N force was removed, and an AP radiograph of the thumb was obtained with a 2 N preload valgus force applied to the thumb, and the angle between the K-wires was measured as a baseline. Subsequently, 20, 40, 60, 80, and 100 N valgus forces were applied to the distal K-wire. At these forces, the estimated torques applied across the MCP joint were 0.3, 0.6, 0.9, 1.2, and 1.5 N-m, respectively. AP radiographs of the thumb were obtained after each force was applied for 1 minute. The angle of displacement between the wires was measured and compared with the baseline angle. The angles were measured with ImageJ (https://imagej.nih.gov/ij/), an imaging processing tool made available by the National Institutes of Health. A custom radial-based thumb MCP-stabilizing orthosis, fabricated with 1/16" nonperforated thermoplastic material (Rolyan Aquaplast Thermoplastic Material; Patterson Medical, Warrenville, IL) immobilizing the thumb MCP but leaving the CMC and IP joints free was fashioned for each cadaveric thumb by a certified hand therapist. The orthosis material was heated in an orthosis pan with water temperature at approximately 154°F until material was pliable and then molded to each cadaveric hand. The orthosis was secured to the hand with KinesioTape (Kinesio Holding Corporation. Albuquerque, NM). The aforementioned loading protocol was then repeated. There were no ligament failures in any of the control or immobilized specimens.

Table 1
Degrees of abduction with each force applied

Applied Force (N)	2 N	20 N	40 N	60 N	80 N	100 N
Unsplinted						
Test 1	10.5	17.7	21.6	22.8	24.1	24.8
Test 2	14.7	27.0	30.2	30.9	29.7	27.7
Test 3	16.7	27.3	31.1	32.3	30.1	31.4
Test 4	4.3	12.8	12.6	30.0	35.1	36.7
Test 5	19.6	27.7	27.6	29.9	30.2	30.5
Test 6	7.7	11.0	14.1	14.2	13.9	14.2
Test 7	5.6	10.4	12.2	12.7	14.3	14.7
Test 8	21.6	37.3	39.4	40.5	42.4	43.2
Test 9	30.8	43.8	47.2	50.1	51.7	52.6
Test 10	28.3	41.3	44.6	46.5	48.3	49.8
Average ± SD (95% CI)	16.0 ± 9.2 (10.3-21.7)	12.5 ± 12.5 (17.9-33.3)	28.1 ± 13.0 (20.0-36.1)	31.0 ± 12.4 (23.3-38.7)	32.0 ± 12.8 (24.0-39.9)	32.6 ± 13.2 (24.4-40.8)
Splinted						
Test 1	2.8	10.9	13.9	17.3	16.8	19.8
Test 2	2.6	7.7	12.3	17.1	17.3	21.7
Test 3	0.1	18.4	27.0	30.6	31.0	31.6
Test 4	0.1	5.7	6.0	10.9	13.2	14.4
Test 5	6.7	14.6	19.3	20.9	21.5	23.6
Test 6	10.1	13.6	15.1	14.6	16.8	17.2
Test 7	1.2	7.0	9.7	11.8	12.0	13.3
Test 8	20.0	25.9	27.6	29.9	31.8	34.3
Test 9	15.8	25.7	29.1	32.7	33.8	36.6
Test 10	7.0	17.5	21.0	23.9	25.5	27.7
Average ± SD (95% CI)	6.6 ± 6.8 (2.4-10.9)	14.7 ± 7.2 (10.2-19.2)	18.1 ± 8.0 (13.1-23.1)	21.0 ± 8.0 (16.0-25.9)	22.0 ± 8.0 (17.0-26.9)	24.0 ± 8.2 (18.9-29.1)

SD = standard deviation; 95% CI = 95% confidence interval.

Statistical methods

A repeated-measures 2-way (load × condition) analysis of variance with a post hoc Sidak's multiple comparisons test was performed to assess mean differences in the abduction angle between the control and immobilized specimens at each applied load. A P value of $<.05$ was defined as statistically significant, a priori. Statistical analysis was performed using Stata/SE 14 (StataCorp, College Station, TX).

Results

The mean thumb MCP abduction of the control group was 15.9° ± 9.2° with a 2 N force, 25.6° ± 12.5° at a 20 N force, 28.1° ± 13.0° at a 40 N force, 31.0° ± 12.4° at a 60 N force, 32.0° ± 12.8° at an 80 N force, and a 33.0° ± 13.2° at a 100 N force (Table 1). The mean normalized thumb MCP abduction of the immobilized group was 6.6° ± 6.8° at a 2 N force, 14.7° ± 7.2° at a 20 N force, 18.1° ± 8.0° at a 40 N force, 21.0° ± 8.0° at a 60 N force, 22.0° ± 8.0° at an 80 N force, and 24.0° ± 8.2° at a 100 N force (Table 1). No ligament failures occurred in either the control or the immobilized groups.

The radial-based thumb MCP-stabilizing orthosis significantly reduced mean abduction angles at each applied load ($P < .05$). There was 41% reduction in abduction angle at 20 N, 35% reduction at 40 N, 31% reduction at 60 N, 30% reduction at 80 N, and 25% reduction at 100 N (Fig. 4).

Discussion

The primary objective of this investigation was to determine if a radial-based thumb MCP-stabilizing orthosis significantly reduces abduction, and thereby indirectly reduces strain, of the thumb MCP UCL up to 100 N. We found that our orthosis, despite being hand-based and leaving the thumb IP and CMC joints free, significantly reduced mean abduction angles at each applied load. We have previously demonstrated that the maximum load to failure of a repaired UCL is 84 N; therefore, this orthosis effectively protects the UCL up to at least 100 N after UCL repair.[20] This investigation provides objective evidence that our radial-based thumb MCP-stabilizing orthosis provides a protective effect at the thumb MCP UCL. In addition, the protective effect conferred by applying a radial-based thumb MCP-stabilizing orthosis may allow early return to work and sport; however, this must be verified with additional investigations that examine how thumb UCL strain corresponds to the thumb MCP abduction angle.

There are several limitations of this investigation. First, repeating loading of the thumb UCL could have stretched the ligament. To minimize this effect, each thumb UCL was preloaded with 100 N for 1 minute before testing. In this initial investigation, the maximum force that was applied to the thumb MCP joint was 100 N. We have previously demonstrated that the maximum load to failure of a repaired UCL is 84 N; therefore, we can infer that this orthosis effectively protects the repaired UCL up to at least 100 N.[20] Nevertheless, future research needs to be

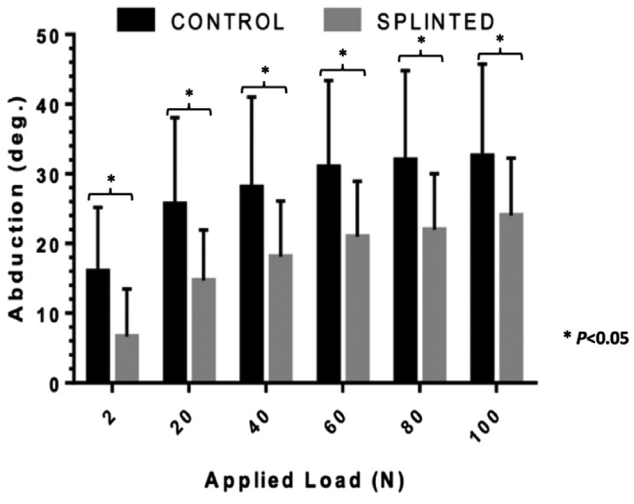

Fig. 4. The radial-based thumb metacarpophalangeal-stabilizing orthosis significantly reduced mean abduction angles at each applied load ($P < .05$). There was 41% reduction in abduction angle at 20 N, 35% reduction at 40 N, 31% reduction at 60 N, 30% reduction at 80 N, and 25% reduction at 100 N.

performed to determine the force at which the orthosis fails to provide a protective effect. Third, this cadaveric model does not account for the effect of the dynamic stabilizers of the thumb MCP and the additional strength generated by the healing process. Fourth, our model forces the thumb to abduct in 1 plane of motion; however, this is consistent with the mechanism of injury for UCL ruptures.

The protective effect conferred by applying the orthosis we tested may allow early return to work and sport. However, this must be verified with additional investigations that examine how thumb UCL strain corresponds to the thumb MCP abduction angle. Future investigations must also examine the effect of dynamically applied load to the splinted MCP.

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1. The type of article is
   a. RCTs
   b. case report
   c. descriptive clinical
   d. basic science in the field of biomechanics
2. The orthotic device crosses
   a. only the CMC joint
   b. only the MCP joint
   c. the MCP and CMC joints
   d. the CMC, MCP, and IP joints
3. Thumb abduction puts stress primarily on the
   a. MCP UCL
   b. MCP RCL
   c. MCP volar plate
   d. EPL
4. The indication of the effect of stress on the target tissue was the
   a. linear gapping of the MCP joint
   b. increased angulation between wires
   c. pain experienced by the subject
   d. number of fibers torn during the maneuver
5. The orthotic devise was shown to reduce abduction of the thumb MCP joint
   a. false
   b. true

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