Single-Bundle vs Double-Bundle (Anatomical) Reconstruction of the Thumb Ulnar Collateral Ligament: Biomechanical Study

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Abstract

Background: The goal of this study is to compare the biomechanical properties of anatomic (double-bundle) versus single-bundle reconstruction of the thumb metacarpophalangeal (MCP) joint ulnar collateral ligament (UCL) in a cadaveric model. **Methods:** Twelve fresh frozen cadaver hands were randomly assigned to single- or double-bundle reconstruction groups using a palmaris longus autograft and tenodesis screws. Two blinded examiners performed mechanical testing and measurements using fluoroscopic imaging. We evaluated MCP joint congruence and angle in the coronal plane at 0°, 30°, and 60° of flexion with valgus loads of 1.36 and 2.72 kg. Maximum MCP flexion and extension with a 0.45 kg load was also measured. **Results:** There was no significant difference between single- versus double-bundle reconstruction in ulnar congruence or MCP angle. With varying amounts of flexion, there was no significant difference in MCP valgus angle between the 2 techniques, suggesting comparable joint congruity and coronal MCP angle along the arc of thumb MCP motion. **Conclusions:** Single- and double-bundle UCL reconstructions of the thumb MCP joint have comparable biomechanical properties in regard to joint congruity under valgus load.

Keywords: metacarpophalangeal joint, ulnar collateral ligament, single-bundle reconstruction, double-bundle reconstruction, cadaveric study

Introduction

Thumb metacarpophalangeal (MCP) ulnar collateral ligament (UCL) injuries occur in approximately 50 per 100 000 people.^{1,4} Ulnar collateral ligament tears result from a hyper-abduction stress to the thumb and are frequently seen in laborers and athletes, with skiing and football as commonly cited sports. Findings indicative of a complete rupture include Stener lesion, valgus laxity of greater than 30°, or a valgus laxity difference of 15° in comparison with the unaffected thumb.^{1,6}

Chronic instability can result from inadequate treatment after acute injury, failure to recognize a Stener lesion, or continued attenuation of the ligament. For acute tears with instability, direct repair is advocated when possible. However, in the setting of chronic instability, direct repair is usually not possible as the ligament tends to shorten and degrade over time. If direct repair is not feasible, ligament reconstruction with a tendon graft is pursued. Options include a double-bundle reconstruction, which attempts to

replicate the proper and accessory UCL (double bundle), or a single-bundle reconstruction of the UCL (single bundle). Although both techniques have been supported in the literature, neither has proven to be superior.^{1,2,6,10}

The goal of this study is to compare the congruity of the MCP joint with single-bundle reconstruction versus double-bundle reconstruction of the thumb UCL in a cadaveric model. Our null hypothesis is that there is no difference in MCP congruity between single- and double-bundle reconstruction techniques.

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Figure 1. Types of UCL reconstruction. (a) Single-bundle reconstruction of the ulnar collateral ligament (UCL) and (b) double-bundle reconstruction of the UCL.

Methods

Twelve fresh frozen unmatched cadaveric hands were randomly assigned to single- or double-bundle reconstruction groups. Thumbs were left attached to the wrists to preserve the extrinsic muscle insertions about the MCP joint. After skin incision, the adductor aponeurosis was divided longitudinally. The proper and accessory collateral ligaments were excised sharply. The insertion and origin footprints were marked with a surgical marker. We then manually applied a valgus force, stressing the MCP joint past 60° to verify complete release.

Two fellowship trained hand surgeons tandemly performed all thumb reconstructions. The first group of 6 cadaver hands underwent single-bundle reconstruction according to the technique described by Carlson et al³ (Figure 1a). Under loupe magnification, two 3.0 mm diameter bicortical holes were drilled—one at the UCL origin and the other in the volar proximal phalanx base. Palmaris longus graft from the specimen was passed through the drill holes using whipstitched passing sutures (3-0 Fiberwire, Arthrex Inc, North Naples, Florida) and a Keith needle. This construct was secured with 1 interference screw at each bone tunnel (3 × 8-mm Tenodesis Screw, Arthrex Inc).

The second group of 6 cadaver arms underwent the double-bundle reconstruction similar to that described by Glickel and colleagues⁵ (Figure 1b). Two 3.0 mm diameter tunnels were drilled in the proximal phalanx base (dorsal and volar to the central axis). A separate 4.0 mm diameter tunnel was placed in the metacarpal UCL origin. A doubled over palmaris longus autograft was pulled into the metacarpal tunnel with a 3-0 Fiberwire loop around the tendon and secured with a 3 × 8-mm tenodesis screw (Arthrex Inc). The 2 free limbs of the palmaris graft were shuttled independently via Keith needle into the phalangeal docking sites, tensioned, and secured with two 3 × 8-mm tenodesis screws.

Both reconstructions were secured with firm manual tensioning in 5° of varus under fluoroscopic guidance. All but 1 cadaver had a palmaris longus. For that cadaver, a palmaris graft from another specimen was used. The skin was closed on all specimens for blinding purposes.

Each thumb metacarpal was mounted to the end of a 2" × 4" wooden board using 2 wood screws placed through the

Figure 2. Experimental setup.

bone, positioning the MCP joint with the UCL reconstruction facing upward and just past the edge of the board so it had unimpeded motion in all planes (Figure 2). A cable tie fastener secured around the thumb tip, at the level of the proximal nail fold, was used to hang weights to load the thumb. Two independent orthopedic surgeons, blinded to the reconstruction technique, tandemly performed mechanical testing and fluoroscopic measurements.

The first experimental setup tested maximum flexion and extension of the MCP joint loaded with a 0.45 kg weight in the sagittal plane. Metacarpophalangeal joint angle was measured on lateral fluoroscopic images.

For the second experimental setup, the MCP joint was manually positioned at 0° , 30° , and 60° of flexion (without weights), and MCP angles were measured in the coronal plane on posteroanterior (PA) fluoroscopic images for baseline alignment reference. Next, at these same angles, the joint was loaded with 1.36 and 2.72 kg weights (radial directed force), and MCP angles were measured in the coronal plane on PA fluoroscopic images (Figure 3). Based on maximum pinch force, we took the maximum and median forces to check for incongruity.⁷ Joint congruence was also measured by comparing joint uncovering at the ulnar and

Figure 3. Radiographic measurements recorded. The posteroanterior projection measures varus/valgus angle and congruence. The “staple” denotes the ulnar congruence measurement. The lateral projection measures maximum flexion and extension.

radial joint lines. Congruency was defined as a less than 1-mm gap difference between both sides of the MCP joint on the PA fluoroscopic images. Joint congruence is crucial for assessment of graft tension and proper graft positioning. If either is insufficient, the joint will open up under loading.

To detect a significant association with a large effect size of 0.8 at 5% significance level, power of 80%, assuming 50% correlation among the repeated measures for 2 groups with 3 measurement in each, we estimated a need for 12 samples (6 in each group) using repeated-measures analysis of variance (ANOVA). Metacarpophalangeal range of motion and coronal angle measurements were recorded based on a consensus of the 2 examiners. Mean measurements were compared between the 2 techniques using independent Student *t* test. Repeated-measures ANOVA was used to compare the valgus angle after incremental increase in MCP flexion from 0° to 60° between the 2 techniques.

Results

Metacarpophalangeal flexion and extension with a standardized force did not show any significant difference between the 2 techniques (Table 1). Normal distribution was checked using 1-sample Kolmogorov-Smirnov test. All variables were normally distributed. The MCP angle (in the sagittal plane) in maximum extension ranged from 0° to 48°, with a mean of 22° for the single bundle and 24° for the double bundle. The MCP angle in maximum flexion ranged from 25° to 70°, with a mean of 48° for both the single- and double-bundle techniques (extension: $P = .82$, flexion: $P = .95$).

Table 1. Radiographic Measurements of Tested UCL Configurations.

Position of MCPJ	Single bundle, mean (SD)	Double bundle, mean (SD)	P value
Full flexion	48° (18°)	48° (6.8°)	.95
Full extension	22° (12°)	24° (17°)	.82
0° flexion	2.3° (4.9°)	5.2° (8.1°)	.48
30° flexion	5.8° (5.0°)	6.8° (8.4°)	.81
60° flexion	5.3° (4.5°)	7.5° (7.3°)	.55
1.36 kg valgus force	22° (16°)	17° (8.6°)	.50
2.72 kg valgus force	31° (19°)	26° (14°)	.62

Note. First metacarpophalangeal valgus angle measurements. UCL = ulnar collateral ligament; MCPJ = metacarpophalangeal joint.

Table 2. Maintenance of Joint Congruency.

Position of MCPJ	Single bundle	Double bundle	P value
Full flexion	6	6	1.0
Full extension	6	6	1.0
0° flexion	6	5	1.0
30° flexion	6	5	1.0
60° flexion	6	5	1.0
1.36 kg valgus force	4	2	.57
2.72 kg valgus force	1	1	.46

Note. The number of joints out of 6 for each technique that remained congruent in different positions and different forces. MCPJ = metacarpophalangeal joint.

There was no statistical difference in MCP valgus angle at 0°, 30°, and 60° of flexion ($P = .40$) in the unloaded condition or after exerting 1.36 and 2.72 kg of valgus force ($P = .41$; Table 1).

Joint congruence was maintained in both the single- and double-bundle techniques with all but 1 of the specimens when a valgus force of 1.36 and 2.72 kg was applied at 0° of flexion. Only 1 specimen with double-bundle reconstruction showed incongruity in all positions; however, the difference was not significant (Table 2). Dislocation or subluxation was not observed in either experimental group.

Discussion

Our goal was to evaluate whether a single bone tunnel on the phalangeal side for thumb UCL reconstruction maintains MCP joint congruency and provides adequate joint stability compared with the double-bundle technique. In our study, there was no statistically significant difference between the 2 groups with respect to MCP valgus angle or ulnar congruence.

Smith described the reconstruction of the single-bundle UCL using Palmaris longus graft with a pullout suture/button construct via bone tunnel.¹¹ Later, based on Littler work, Glickel and colleagues described a double-bundle reconstruction using a triangular configuration with the goal to limit valgus angulation, volar subluxation, and supination of the proximal phalanx.⁵ However, there is risk of fracture as a result of the small bone bridge between the phalangeal tunnels. Thus, the double-bundle technique may require more

precision and can be more technically demanding. One biomechanical cadaveric study by Carlson et al demonstrated that a single-bundle reconstruction with Palmaris longus graft adequately restores UCL function.³ However, others advocate the double-bundle reconstruction which aims to recreate both the proper and accessory UCLs.⁹ Although many previous biomechanical studies report on either single- or double-bundle reconstruction, our study is one of the first to compare the 2 reconstructions.

Hogan et al performed a study comparing various reconstruction techniques and found that the modified Glickel procedure (anatomic double-bundle reconstruction) had a higher moment to failure and was significantly stiffer, affirming the possible advantage of the double-bundle technique.⁸

Our results are similar to a previous biomechanical cadaveric study performed by Baskies et al who compared a cruciate reconstruction technique versus single-bundle repair.² The cruciate reconstruction is not an anatomic repair and thus differs from our study. In addition, our technique evaluated MCP congruency and angulation with minimal restraint of the joint and with only gravity-driven loading. This “open chain” setup allowed for potential subluxation, dislocation, or rotational instability that would not have been apparent if both the metacarpal and the proximal phalanx were secured. Finally, in our study, we kept the upper limb attached to the thumb to account for all soft tissues proximal to the MCP joint, which also exert forces on the joint.

Our experimental setup had several limitations. Complete division of the UCL with forced gapping of the MCP joint past 60° in each cadaver prior to the experiment helped minimize interspecimen variability. In addition, inherent variability in the mechanical characteristics of these non-matched cadaver joints could have influenced our results. Although it may be challenging to determine the effect of the volar plate versus the UCL at 0° of flexion, it is likely that the volar plate was compromised with the initial 60° forced angulation of the MCP joint, but this should affect both groups similarly. Another potential limitation of this study is the elimination of the adductor aponeurosis as an additional stabilizer, because it was not repaired; however, both groups were treated in a similar fashion. In contrast to other studies, we retained the anatomic relationship of the thumb to the hand, leaving the soft tissue envelope and other ligaments intact. The sample size was too small to run multiple hypotheses, therefore our secondary hypotheses were likely underpowered.

In conclusion, our study suggests that, in a cadaveric model, single- and double-bundle reconstructions are comparable options for UCL reconstruction, and there is no noticeable difference in MCP congruity when loaded. Prospective randomized studies should further evaluate whether these biomechanical results have clinical application.

Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Statement of Informed Consent

Informed consent was not needed for this cadaveric study.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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