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Comparison of in-vitro motion and stability between techniques for index metacarpophalangeal joint radial collateral ligament reconstruction

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Abstract

Purpose—To evaluate a technique using interference screws to reconstruct the radial collateral ligament (RCL) of the index finger metacarpophalangeal (MP) joint. We hypothesized that this technique would provide equivalent stability and flexion as a 4-tunnel reconstruction.

Methods—The RCL was isolated in 17 cadaveric index fingers. A cyclic load was applied to the intact RCL across the MP joint to assess flexion, ulnar deviation at neutral (UD@0), and ulnar deviation at 90° of MP joint flexion (UD@90). The RCL was excised from its bony origin and insertion. Each reconstruction (4-tunnel and interference screw) was performed sequentially on each specimen in randomized order. Testing was repeated after each reconstruction. Differences from the intact state were compared between the techniques using paired t-tests for all joint positions (flexion/UD@0/UD@90).

Results—There was no statistically significant difference in UD@0 or UD@90 between the intact state and after interference screw reconstruction. Compared to the intact state, there was significantly less UD@0 and significantly more UD@90 after 4-tunnel reconstruction. There was no statistically significant difference between techniques when comparing change in -UD@0 or change in UD@90. Change in flexion was statistically significantly different, indicating that the interference screw technique better replicated intact MP joint flexion compared to the 4-tunnel technique.

Discussion—Interference screw reconstruction of the index RCL provided stability comparable to 4-tunnel reconstruction but is less technically challenging. These results substantiate our clinical

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experience that interference screw technique provides an optimal combination of stability and flexion at the index MP joint.

Clinical Relevance—Using an interference screw to reconstruct the index RCL is less challenging and provides stability and range of motion that closely resembles the native MP joint.

Keywords

RCL; index finger; ligament; anatomy

Introduction

Injuries to the radial collateral ligament (RCL) of the index finger metacarpophalangeal (MP) joint are rare, though possibly underreported, with 34 cases reported in the literature. (1-6) Although not encountered on a regular basis, prompt identification and treatment of patients with unstable index MP joints is important to avoid progressive instability and pinch weakness. (2) Gaston advocated for early repair of the RCL in clinically unstable index MP joints. (2) However, uncertainty remains regarding the preferred surgical techniques and subsequent outcomes, as there is limited information regarding long-term follow-up. (3)

While primary repair of the native RCL is preferable and usually feasible in the acutely injured finger, attenuated or contracted tissues of a chronic injury may necessitate RCL reconstruction. (7) The specific challenge of reconstructing the index RCL is to balance the radial/ulnar stability with preservation of MP joint motion. Many of the techniques previously used to reconstruct the index RCL have been derived from the thumb MP ulnar collateral ligament and may not meet this challenge, given the differences given the differences in the demands placed on the index finger compared to the thumb. The index finger MP joint has a greater range of motion than the thumb (8, 9), and the cam effect of its bony morphology affects collateral ligament length (10). Additionally, the longer lever arm of the index finger subjects the MP joint to greater stress when force is applied at the fingertip. An index-specific RCL reconstruction used 4 bone tunnels (11), which can make restoration of the intact RCL difficult due to a more horizontal orientation of 1 limb of the graft compared to the intact ligament. Additionally there is potential for greater laxity of this reconstruction as a long graft is woven through each tunnel and sutured to itself. In view of the emergence of other technologies for soft tissue fixation, such as suture anchors (12-15) and interference screws (16,17), we have developed a technique for index RCL reconstruction that uses interference screws to secure the graft to the anatomic origin and insertion of the native ligament. We hypothesized that the interference screw technique for index RCL reconstruction would provide equivalent radial/ulnar stability and flexion range of motion (ROM) as a 4-tunnel reconstruction and would likely be easier to perform.

Materials and Methods

Seventeen fresh-frozen human cadaveric index fingers were disarticulated at the carpometacarpal joint. An a-priori sample size calculation determined that 15 specimens would be needed to detect a difference of 10 degrees (which is a clinically appreciable difference) with 80% power. (17) Two additional specimens were available and were included in the investigation. The specimens were dissected using a direct mid-axial approach. The index finger RCL was exposed while minimizing damage to the joint capsule and surrounding soft tissue envelope. The palmar plate, deep transverse intermetacarpal ligaments, and checkrein ligaments were left intact. The first dorsal interosseous muscle was detached from its origin from the second metacarpal. The metacarpal base was potted in air hardening putty (Bondo® body filler, 3M, Atlanta, GA), and specimens were mounted in a uniaxial servohydraulic test machine (MTS, Eden Prairie, MN). (Figure 1) The extensor and

flexor tendons were loaded to 700g and 200g, respectively to reproduce physiologic compression across the MP joint, as previously performed in biomechanical studies on index finger RCL reconstructions.(11)

To ensure contact between the load applicator and the specimen, specimens were preloaded with a 0.5N force, and a half-sine cyclic waveform of 4.5N was applied at 1Hz. Loads were applied 15mm distal to the MP joint line. The preload was chosen to be 10% of our maximum applied load and was determined to be nondestructive based on pilot tests. Our maximum target load was designed to meet 2 criteria: 1. The load had to be low enough to destroy the remaining joint stabilizers in flexion and ulnar deviation. 2. The load had to generate a moment at the joint that would encourage motion in flexion and ulnar deviation within a measurable range (enough deviation to allow detectable differences between the conditions, but avoiding MP flexion greater than 90° because our setup would not allow us to apply further load). We used an indelible marker to indicate the distance from the joint line at which the load should be applied. Our positioning jig and potting method enabled us to reproducibly orient and locate the plunger on the specimen through controlling the distance from the joint line to the potting (location) and using uniqueness in the geometry of the potted end of the joint (orientation).

To control for maintaining the plunger location on the specimen, the plunger had a 5mm radius so that as the finger flexed, the plunger remained in contact with the specimen at our marked line throughout testing. A 5N cyclic load was applied along the radial surface of the specimen to apply a varus-deforming force. This test was performed in 0° and 90° of MP joint flexion. The magnitude of ulnar deviation of the proximal phalanx was measured from the displacement of the crosshead of the servohydraulic test machine. The joint was repositioned to neutral MP joint flexion, and a 5N cyclic load was applied to the dorsal surface of the proximal phalanx 15mm distal to the MP joint line. The magnitude of flexion of the proximal phalanx was measured from the displacement of the crosshead of the servohydraulic test machine.

A total of 10 cycles of load were applied during each test, with measurements taken during the tenth cycle. In our pilot testing, we noted that 3 cycles were needed to establish a steady load-displacement curve. Because no changes in tissue integrity or ROM were observed when the specimen was cycled beyond 10 times in pilot testing, we chose to use measurements from the tenth cycle.

Following completion of nondestructive intact testing, we excised the proper RCL from its bony origin and insertion. The ligamentous footprint of each attachment point of the proper RCL was marked with an indelible marker to facilitate identification of the center point for later use while performing the RCL reconstructions. The accessory RCL was excised from each specimen, leaving the palmar plate intact. We performed 2 RCL reconstructions: a 4-tunnel reconstruction (11) and an anatomic reconstruction using interference screw fixation at the center of the RCL origin and insertion sites. The surgical techniques were performed in a manner that allowed both techniques to be performed in the same specimen to enable repeated measures analysis. Two of the drill holes for the 4-tunnel technique were the same location as the 2 holes needed for the interference screw technique. Performing both reconstructions on the same specimen was not destructive and allowed us to avoid inter-specimen variability of the osseous structure and soft tissue envelope surrounding the MP joint when comparing the stability and flexion differences between the 2 techniques. The order of reconstructive technique to be performed first in each specimen was randomized.

Four-Tunnel Technique

Two unicortical tunnels were drilled using a 3.2mm drill at the insertions of the native RCL on the metacarpal and proximal phalanx. If bicortical tunnels were previously drilled for the interference screw technique, the same tunnels were used. The second set of holes (unicortical) were made on the metacarpal and proximal phalanx 10mm from the anatomical origins of the RCL as originally described by Hsieh, et al.(11) Digital calipers were used to measure the locations of the second set of holes prior to any drilling. A palmaris longus tendon was passed through the 4 bone tunnels, and the graft was tensioned within the tunnels by pulling along the graft limbs. The MP joint was positioned in 30 degrees of flexion without any radial or ulnar deviation of the proximal phalanx during graft tensioning (as performed by the senior author (MGC) in clinical practice). The graft limbs were tied with half-hitch knots and secured with 2-0 non-absorbable suture. (Figure 2) The knot securing the graft limbs was placed along the extra-articular aspect of the reconstruction, and the excess graft was trimmed. The reconstructed tendon graft was then sutured to the volar plate with a single 2-0 suture to emulate the orientation of the accessory RCL.

Interference Screw Technique

Similar to the bone tunnel technique, 2 tunnels were drilled using a 3.2mm drill at the attachments of the native RCL on the metacarpal and proximal phalanx. If these tunnels were previously drilled for the 4-tunnel technique, the same tunnels (those closest to the MP joint) were used. However, bicortical (radial and ulnar cortices) tunnels were created for this technique. A running, interlocked suture was placed on both ends of the palmaris longus tendon. The distal 4cm of the palmaris longus graft provided ideal graft length and width. A Keith needle was used to pass the suture and tendon graft through the bicortical tunnels. After piercing the skin on the opposite side of the finger, the sutures were grasped and used to tension the tendon graft with the MP joint in 30 degrees of flexion without any ulnar or radial deviation of the proximal phalanx. A formal counter-incision was not necessary. While the graft was tensioned, a 3mm × 10mm interference screw (Rattler™ Interference Screw System, Biomet Sports Medicine™, Warsaw, IN) was inserted flush to the bone into both metacarpal and proximal phalanx tunnels. (Figure 3) The tendon graft was then sutured to the volar plate with a single 2-0 suture to emulate the orientation of the accessory RCL. (Figure 4)

Additional Testing

Each specimen underwent the same battery of mechanical testing after each reconstruction. The amount of ulnar deviation permitted at neutral MP joint flexion (UD@0), ulnar deviation permitted at 90° MP flexion (UD@90), and total flexion of the MP joint were recorded.

Statistical Analysis

The amount of ulnar deviation at neutral and 90° flexion and MP joint flexion in each specimen was compared before and after each reconstructive technique. Additionally, the differences from the intact state (change in-UD@0, change in-UD@90, change in flexion) were compared between the 2 reconstruction techniques. All comparisons were made using 2-tailed paired t-tests. Using the extreme studentized deviate test, the statistically significant outliers among the measured values were identified and removed (2 outlying values of 102 total data points collected) prior to statistical analysis.

Results

Stability (Ulnar Deviation Testing)

There was no statistically significant difference in UD@0 or UD@90 between the intact state and after interference screw reconstruction. There was significantly less UD@0 (more stability in neutral) after the 4-tunnel reconstruction compared to the intact state ($33^{\circ} \pm 11^{\circ}$ vs. $40^{\circ} \pm 11^{\circ}$; $P=0.02$). There was significantly more UD@90 (less stability in flexion) after the 4-tunnel reconstruction compared to the intact state ($P=0.03$). There was no statistically significant difference in the change from the intact state of ulnar deviation at neutral (change in-UD@0) between the 2 reconstructive techniques. There was also no statistically significant difference in the change of ulnar deviation when the MP joint was flexed to 90° (change in-UD@90) between the 2 reconstructive techniques. The measured values of ulnar deviation in both testing positions are shown in Figure 5.

Range of Motion (MP Flexion Testing)

There was no statistically significant difference in MP joint flexion between the intact state and either reconstruction technique. There was a statistically significant difference ($P=0.03$) between the 2 reconstructive techniques for change in flexion from the intact state (change in flexion). There was less flexion compared to intact after the four-tunnel reconstruction and more flexion compared to intact after the interference screw reconstruction. The measured values of MP joint flexion are shown in Figure 5.

Comparison based on the order of testing (four-tunnel reconstruction performed first vs. interference screw reconstruction performed first) did not reveal differences in UD@0, UD@90, or total MP joint flexion.

Discussion

Index RCL reconstruction using an interference screw can provide radial/ulnar stability that is not different from that provided with a 4-tunnel reconstruction. Our findings should be carefully interpreted. The combination of (1) an absence of a statistically significant difference between the measured UD values of the intact state and after interference screw reconstruction and (2) significant differences between the measured UD values of the intact state and after four-tunnel reconstruction does not indicate that the interference screw provides superior stability than the four-tunnel technique. Comparison of the measured values shows no clinically meaningful difference between the 2 reconstruction techniques. To supplement the interpretation of these results, we analyzed the change from intact (change in-UD@0, change in-UD@90) to compare the 2 techniques and found no difference between the interference screw and 4-tunnel technique. Although both reconstructions provide comparable stability, we feel that the primary advantage of the interference screw reconstruction is that it is technically easier, as only 1 drill hole is needed on the metacarpal and phalangeal side and weaving of the graft is not required.

Successful long-term results have been seen with a 2-tunnel technique for collateral ligament reconstruction in the digits.(3) However, only 3 of the reconstructions in Rierderer's study were performed for the index MP joint RCL, and individual results for each reconstruction were not presented. The success seen in Rierderer's series may be due to the fact that only 2 tunnels were created at the origin and insertion of the native RCL, allowing replication of the native ligament orientation. The interference screw technique used in the current investigation is similar to Rierderer's technique with a more facile fixation of soft tissue to bone. Interference screw technology has shown a wide diversity in its utility, as it has been used successfully for reconstruction of the anterior cruciate ligament of the knee (18) and the ulnar collateral ligament of the elbow (19). A biomechanical study

using similar methods has demonstrated the efficacy of interference screw reconstruction for the ulnar collateral ligament of the thumb MP joint (17), and this technique can be adopted for reconstruction of the collateral ligaments in other finger joints.

The current study has several limitations. As a biomechanical cadaveric study, our experiment is only representative of the time zero point after completion of the reconstruction and does not account for the effect of postoperative healing and rehabilitation on joint stability and ROM. Additionally, we did not test the ligaments to failure, as healing of the ligament reconstruction is critical to the strength of the repair. Another limitation inherent to the biomechanical testing protocol is that application of additional load beyond 5N may increase the overall resultant ROM, potentially revealing greater differences between the tested states. However, we used this load to maintain a nondestructive testing protocol. Although there may be other reconstructive techniques that provide sufficient stability and motion, we chose to include only 2 in the current study. The interference screw technique was chosen based on our positive clinical experience, and the 4-tunnel technique was selected because it was the only index RCL-specific reconstructive technique in the literature. (11) Future studies may choose to compare additional techniques. While other surgeons have used bone tunnels that straddle the native insertion points of the collateral ligaments (10), such insertion points have only been described for the thumb and not for the index finger. Both of the reconstructions we tested include common drill paths through the origin and insertion of the index RCL. This was done to replicate the only described technique for index RCL reconstructions, described by Hsieh, et al (8) and the technique that we use clinically for the interference screw technique. Additionally, the reader should consider that primary ligament repair is preferred over reconstruction if the remnant tissue is suitable. Ligament repair can be achieved with direct suturing or using suture anchors if avulsion injury has occurred. While suture anchors are an alternative to interference screws during ligament reconstruction, it is our opinion that the former are less reliable in situations that demand fixation on 2 ends of a tendon graft. Lastly, we sacrificed the first dorsal interosseous muscle, an additional radial-sided stabilizer of the index MP joint to isolate our evaluation of the RCL. The loss of this dynamic stabilizer may compromise the ability of our model to simulate the in-vivo scenario.

A strength of our study was that we were able to perform both reconstructions in each specimen in a randomized fashion. This allowed us to isolate the effect of the reconstructive techniques on stability and ROM using repeated measures, as the osseous structure and soft tissue envelope surrounding the MP joint were not subject to inter-specimen variability.

A few technical points should be recognized when using the interference screw technique to treat index RCL injuries. The tunnels should be drilled through both the near and far cortices, not just to the depth of the implant. In our experience, drilling only to the depth of the implant (even for only 1 tunnel) makes it extremely challenging to tension the graft while inserting the screws, as the surgeon is unable to maintain direct control of the graft, and it may bunch inside the drill hole. Using bicortical tunnels allows the surgeon to easily tension both limbs of the graft (usually with an assistant holding equal and simultaneous tension on both limbs while the surgeon inserts the screws) and avoids the need to exactly measure the graft length, as excess graft material will be pulled through the tunnels. Additionally, the joint should be positioned in 30° of flexion without any radial/ulnar deviation. We have found that this position allows a maintained reduction of the MP joint during tensioning of the graft. If the graft is tensioned with the MP joint in extension, the proximal phalanx tends to subluxate dorsally. Furthermore, we found that the distal 4cm of the palmaris longus graft provides ideal graft length and width. If more than 4cm is used the graft may remain redundant under the skin. If the proximal wide portion of the Palmaris longus tendon is chosen, the graft may not fit in the drill tunnels. When using the Arthrex

Rattler interference screw (3mm × 10mm), the tunnel should not be enlarged because the drill bit size (3.2mm) is predetermined by the manufacturer to allow an interference fit of tendon to bone with the screw inserted. We do not have any experience using a larger drill bit or a longitudinally-split tendon graft for index RCL reconstruction and leave this to the discretion of the treating surgeon. Lastly, if the surgeon notes grossly osteoporotic bone during drilling for interference screws, he or she should consider converting to the 4-tunnel technique to avoid interference screw and tendon graft loosening. We have not yet encountered this situation and anticipate that it would be rare, given that index RCL injuries tend to occur in younger, athletic populations.

Our findings suggest that the interference screw technique does not compromise stability and range of motion compared to the 4-tunnel technique and is technically easier. Based on our experience, the interference screw technique can be more quickly performed than the four-tunnel technique, by eliminating the technical difficulty of weaving the graft. While adjustment of the position of the second set of tunnels or any other alteration of the tunnel number or configuration may change the resultant motion after four-tunnel reconstruction, this was not the subject of our investigation as we sought to compare an existing technique specific to the index RCL to the interference screw technique. The 4-tunnel technique also increases the risk of fracture during tunnel creation (11), and the additional bony work may promote postoperative stiffness by increasing the inflammatory response. In addition to the cost of the implants, another drawback to using the interference screw is the risk of foreign body reaction such as osteolysis, which has been previously described with suture anchors used in hand surgery.(5,20) Nonetheless, these biomechanical results substantiate our clinical experience that the interference screw technique provides an optimal combination of stability and flexion at the index MP joint.

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Figure 1.

Illustration of the 4-tunnel reconstruction technique. The tendon graft is passed through the bone tunnels and tensioned in 30° of flexion. The dashed lines denote where the graft is in the intramedullary canal. A graft is sutured to the volar plate. The proximal phalanx is depicted on the left, and the metacarpal on the right.

Figure 2. The first interference screw is first placed in the phalanx. The graft is then tensioned with the MP joint in 30° of flexion, and the second interference screw is placed in the metacarpal. Sutures emanating from the contra-lateral side are cut off at skin level.

Figure 3.

A suture is placed between the reconstructed collateral ligament and the volar plate. The proximal phalanx is depicted on the left, and the metacarpal on the right.

Figure 4.

Average MP joint flexion and ulnar deviation with the joint in both neutral and 90 degrees MP flexion for the the intact and reconstructed radial collateral ligaments.