Biomechanical Comparison of Suture-Button Suspensionplasty and LRTI for Basilar Thumb Arthritis

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Abstract

Background: The purpose of this study was to compare the initial biomechanical strength of trapeziectomy and suture-button suspensionplasty (SBS) with ligament reconstruction and tendon interposition (LRTI) for thumb carpometacarpal (CMC) arthritis in a cadaveric model. **Methods:** Eight matched pairs of below-elbow cadaveric arms were used for this study. Each specimen was randomly assigned to either receive a trapeziectomy and LRTI (LRTI group) or trapeziectomy and SBS (SBS group). Using previously described and validated testing protocols, physiological key pinch was simulated. The thumb metacarpal was then incrementally loaded from 5 to 20 lbs, using 5-lb increments. Metacarpal subsidence during physiological key pinch and incremental loading was determined using radiographic measurements of trapezial space height. **Results:** The average pretesting trapezial space height did not differ significantly between the LRTI (11.9 mm) and SBS (13.7 mm) groups. After simulated physiological key pinch, the SBS group had significantly greater average trapezial space height compared with the LRTI group (8.0 mm vs 5.5 mm). For each incremental metacarpal load from 5 to 20 lbs, the SBS group had significantly greater average trapezial space height than the LRTI group. **Conclusions:** In a cadaveric model, SBS demonstrates greater resistance to metacarpal subsidence with immediate loading compared with LRTI.

Keywords: suture-button suspensionplasty, basilar thumb arthritis, Mini TightRope

Osteoarthritis (OA) at the base of the thumb can cause severe pain, weakness, and deformity and can result in marked disability.¹⁴ The unique anatomy of the thumb carpometacarpal (CMC) joint predisposes it to degenerative arthritis.^{5,27} Specifically, the degree of weakening of the palmar beak ligament has been correlated with degenerative processes in the joint and is the target of ligament reconstruction for symptomatic arthritis.⁷

Degenerative OA at the thumb CMC joint is treated initially with activity modification, splinting, medication, and intra-articular corticosteroid injections.³⁴ For advanced disease, or when nonoperative treatments have failed, surgical intervention can be considered. Surgical options include volar ligament reconstruction,¹¹ first metacarpal osteotomy,¹³ CMC joint arthrodesis,¹² total joint arthroplasty,¹ and trapeziectomy with or without ligament reconstruction and tendon interposition (LRTI).^{3,9} Comparative studies have shown no significant long-term difference in outcomes among these techniques,^{18,29-31} aside from a lower complication rate^{30,31} and shorter operative time with trapeziectomy alone.²⁰

The use of a suture-button suspensionplasty (SBS) with trapeziectomy has grown in popularity.^{6,24,35,36} Advocates of this technique cite safety, ease of use, early mobilization, and good early results.^{35,36} However, it is not known how effectively the SBS withstands metacarpal subsidence under loaded conditions. The purpose of this study was to biomechanically compare the more widely adopted LRTI procedure with SBS using a cadaveric model. We hypothesize that the SBS will result in a biomechanically stronger construct with immediate loading. Demonstration of an enhanced ability to withstand early active pinch while preventing metacarpal subsidence may support early motion rehabilitation protocols.

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Materials and Methods

We obtained institutional review board approval for this study and used 8 matched pairs of fresh-frozen below-elbow cadaver arms in this study. All specimens were examined and found to have no history of any prior basilar thumb or wrist procedures. The specimens were prepared as described by Luria et al.¹⁷ The extensor pollicis longus (EPL), extensor pollicis brevis (EPB), flexor pollicis longus (FPL), and the adductor pollicis (AP) tendons were prepared as the muscle-tendon units given their role in simulating key pinch.⁴ A 2.0 FiberWire suture (Arthrex, Naples, Florida) was placed in each tendon using a Krackow stitch to facilitate loading (Figure 1).

One specimen in each matched pair was randomly assigned to either the LRTI or SBS group. Each LRTI was performed using the technique described by Burton and Pellegrini.³ The SBS group underwent a trapeziectomy and SBS using the Mini TightRope (Arthrex) as described by Cox et al.⁶

Each specimen was then mounted using a clamp holding the proximal radius and ulna. We used previously described and validated testing protocols to simulate key pinch of approximately 32 N.^{4,17,22,23} Load was applied using fishing line and weights attached to the sutures in each muscle-tendon unit (EPL: 2.5 lbs; EPB: 2.5 lbs; AP: 2.5 lbs; FPL: 5 lbs; total: 12.5 lbs) as described by Putnam et al to generate pinch (Figure 2).²³

After simulation of key pinch, the first metacarpal was axially loaded in an incremental fashion utilizing a 2.0-mm Steinman pin placed through its middle third from dorsal to volar. Increasing weight was sequentially added to the pin in 5-lb increments, to a maximum load of 20 lbs, with the goal to maximally load the metacarpal and axially stress the reconstruction.

We obtained 30° supinated anteroposterior C-arm images in the following scenarios: (1) intact trapezium with simulated key-pinch load applied, (2) postoperatively with no load applied, (3) postoperatively with simulated key-pinch load applied, and (4) postoperatively with simulated axial loading of the metacarpal at 5-lb increments to a maximum of 20 lbs (Figure 3). The trapezoidal space height was measured for each image and used to quantify metacarpal subsidence as described by Downing and Davis.⁸ Using open source digital software (Image J, NIH), trapezoidal space height was measured from an orthogonal line from the long axis of the scaphoid at the distal articular surface and a parallel line that bisected the proximal first metacarpal articular surface at the midline (Figure 3).² The trapezoidal space height was independently measured twice and averaged for each testing state. The percent decrease in trapezoidal space height from the preloaded state was also calculated for each load. Statistical analysis was performed using a paired *t* test.

Figure 1. Illustration of muscle-tendon units involved in simulating key pinch.

Source. Illustration adapted from Luria et al.¹⁷

Note. A 2.0 FiberWire (Arthrex, Naples, Florida) was Krackow stitched through the FPL, EPB, EPL, and AP tendons. To ensure an adequate line of pull, the suture through the AP was routed subcutaneously and passed over a k-wire placed into the hamate to act as a pulley. Fishing line was used to attach weight to the FiberWire suture to load the muscle-tendon units with a line of pull in the direction of the arrows. A total of 6 k-wires were used to stabilize the hand and wrist. These were placed across the radiocarpal (not pictured) and ulnocarpal (not pictured) articulations to prevent wrist flexion/extension, proximal to the distal radioulnar joint (not pictured) to prevent rotation, across the index and long metacarpophalangeal joints with joints positioned at 90° of flexion to resist pinch, and into the hamate to act as a pulley for our AP line of pull. An additional 2 k-wires were placed parallel into the scaphoid and first metacarpal to gauge thumb rotation under load as described by Luria et al.¹⁷ We discontinued the use of these k-wires, as the measurement of rotation was too subjective and unreliable. EPL = extensor pollicis longus; AP = adductor pollicis; EPB = extensor pollicis brevis; APL = abductor pollicis longus; FPL = flexor pollicis longus; FCR = flexor carpi radialis; k-wire = Kirschner wire.

Results

Five male and 3 female matched-pair below-elbow specimens were tested. The age of the cadavers ranged from 36 to 72 years, with an average age of 56 years.

The average native trapezoidal space height was similar between the LRTI and SBS groups (14.6 mm vs 14.7 mm,

Figure 2. Line drawing depicting the experimental apparatus. Note. The specimen was held by a tabletop clamp. Weights are suspended from a fishing line clipped to the 2.0 FiberWire (Arthrex, Naples, Florida) through the muscle-tendon units.

$P = .9$). Following trapeziectomy and either intervention, the unloaded average trapezial space height did not significantly differ between the LRTI and SBS group (11.9 mm vs 13.7 mm, $P = .4$).

During simulated physiological key pinch, metacarpal subsidence was evident in each specimen. The SBS group maintained a significantly greater average trapezial space height (8.0 mm) compared with the LRTI group (5.5 mm, $P = .04$; Table 1).

Following incremental loading of the metacarpal, the SBS group maintained significantly greater average trapezial space height than the LRTI at each weight increment. For both groups, the percent change in the trapezial height increased linearly as the weight increased (Figure 4).

Failure was noted in 1 specimen in the SBS group at the 20-lb metacarpal loading increment. The knot failed at the suture button overlying the index metacarpal. No other failures were noted.

Discussion

This experiment showed that SBS was biomechanically stronger in resisting metacarpal subsidence under immediate loading as compared with the standard LRTI in a cadaveric model. This finding was evident both under physiological loading for key pinch and incremental axial metacarpal loading.

A variety of surgical techniques have been described for the treatment of basilar thumb OA. Pain relief, stability, mobility, and strength remain the primary goals of treatment. Since the original description nearly 30 years ago, Burton and Pellegrini's LRTI remains the most widely used procedure for CMC arthritis.²⁹ The technique requires

Figure 3. Radiograph of specimen under testing of key pinch. Note. The radiopaque marker is a quarter taped to the specimen and is used as measurement reference. The trapezial space height was measured for each image and used to quantify metacarpal subsidence as described by Downing and Davis.⁸ Using open source digital software (Image J, NIH), trapezial space height was measured from an orthogonal line from the long axis of the scaphoid at the distal articular surface and a parallel line that bisected the proximal first metacarpal articular surface at the midline.²

Table 1. Average Trapezial Space Height (mm) for Both Groups Preoperatively and Postoperatively During Testing of Simulated Key Pinch.

Group	Preop loaded	Postop unloaded	Postop loaded
LRTI group	14.6	11.9	5.5
SBS group	14.8	13.7	8
	$P = .9$	$P = .4$	$P = .04$

Note. Preop = preoperatively; Postop = postoperatively; LRTI = ligament reconstruction and tendon interposition; SBS = suture-button suspensionplasty.

harvesting the flexor carpi radialis (FCR) tendon and weaving it through a bone tunnel at the base of the thumb metacarpal to recreate the volar beak ligament. In theory, this reconstruction maintains the trapezial space height after resection of the trapezium thereby improving thumb strength. However, compared with trapeziectomy alone, trapeziectomy with LRTI does not demonstrate any superiority.^{18,31} In addition, adverse events such as scar tenderness, tendon adhesion or rupture, sensory changes, or complex regional pain syndrome type 1 have been reported to occur in 22% of patients after LRTI compared with 10% of patients after trapeziectomy only.^{30,31}

Furthermore, there is controversy as to the sequelae of harvesting the FCR. Naidu et al examined the effects of harvesting the entire FCR tendon and used the contralateral

Figure 4. Comparison of the average change in trapezial space height between the LRTI and SBS groups after simulated pinch and incrementally increasing axial loads to the first metacarpal.

Note. A higher percentage indicates a greater loss of trapezial space height and collapse of the first ray. LRTI = ligament reconstruction and tendon interposition; SBS = suture-button suspensionplasty.

*Statistical significance, $P < .05$.

extremity as the control.¹⁹ These authors found that the control extremity had 2.5 times greater wrist flexion fatigue resistance than that of the surgically treated side. They also found that the surgical side showed a significantly lower wrist flexion-to-extension peak torque ratio than that of the control extremity. Other studies have reported no secondary deficits after FCR harvest.^{26,28}

SBS was initially described to replace Kirschner wire (k-wire) stabilization of the thumb metacarpal following arthroscopic trapeziectomy.⁶ The authors cited the need for a buried implant to allow earlier mobilization and avoid pin site infections as percutaneous k-wires remain in place for a minimum of 4 weeks. Using a cadaveric model of lateral pinch, Yao et al showed similar metacarpal stability with both SBS and percutaneous k-wire insertion after trapeziectomy.³⁷

Complications of the suture-button device used in the foot and ankle have been reported in the orthopedic literature. Inadequate fixation and foreign-body reactions from the suture-button placement have been reported.^{10,16,25,32} Fracture of the index metacarpal has also been reported following SBS.^{15,36} Since those reports, the Arthrex second-generation Mini TightRope kit includes a 1.1-mm guidewire to drill the metacarpal instead of the 2.7-mm drill used in the earlier systems. Since the change to a guidewire from the larger drill, no fractures have been reported.³⁶

In a series of 21 patients with a minimum of 2-year follow-up, Yao et al reported favorable results of SBS.³⁶ Their postoperative protocol allowed therapist-directed range of

motion exercises 10 days after surgery. The authors reported that subjective and objective outcome measures were similar to previously described techniques, including LRTI. Two complications were reported in a single patient: complex regional pain syndrome and index metacarpal fracture 3 months postoperatively, both of which resolved by 10 months. The fracture occurred prior to the implementation of the second-generation Mini TightRope system.

Some authors have expanded the use of SBS to include 2 Mini TightRopes. A series of 11 patients (12 thumbs) demonstrated satisfactory pain reduction, grip strength, and preserved range of motion.²¹ Trapezial space height was maintained from preoperative levels at an average of 17 months postoperatively. They reported no cases of fracture, but 3 patients had dysesthesias and 1 developed complex regional pain syndrome.

Overall, the long-term clinical effect of postoperative metacarpal subsidence is thought to be minimal. Yang and Weiland reported that despite a 32% decrease in trapezial space height, patients still had a 17% improvement in pinch and grip strength.³³ However, the theorized ability of the SBS to withstand metacarpal subsidence is cited by advocates of this technique.³⁴ Authors report that with increased resistance to subsidence, an early motion protocol can be used.³⁴ The results of this study showed that SBS is biomechanically superior to the LRTI procedure in withstanding metacarpal subsidence in simulated physiological pinch and incremental metacarpal loading immediately following the procedure supporting an early motion protocol. In addition,

the trapezial space height decreased in a linear fashion as the metacarpal was incrementally loaded in both groups.

Clinical studies have shown that SBS is a safe and effective technique for the treatment of basilar thumb arthritis.^{21,36} To date, there are no long-term data to support one surgical option over the other (or any surgical options for basilar thumb arthritis). The authors of these clinical series have adopted an early mobilization protocol, with range of motion starting as early as 10 days and the goal of earlier recovery. The results of this study would support the early mobilization protocol due to the biomechanical strength of SBS.

The overall cost differences of the 2 procedures should also be considered. Although this is not a study of cost analysis, the SBS does require the purchase and additional cost of an implantable device. However, by not having to harvest the FCR tendon for an LRTI, the overall operating room (OR) time may be shortened, thus decreasing OR costs.

There are limitations to this study. A validated physiological key-pinch testing protocol was used along with a novel (but unvalidated) method of incrementally loading the metacarpal to force subsidence. While testing, it was noted that metacarpal rotation was not controlled at the heavier loads. The effect of this rotation is uncertain. Furthermore, scar tissue is likely to augment the resistance of metacarpal subsidence following an LRTI procedure and cannot be tested in a biomechanical setting.

In addition, an initial attempt was made to assess the 2 procedures' effect on metacarpal rotation during pinch at physiological loads. Using the protocol of Luria et al, 2 parallel k-wires were placed into the metacarpal and scaphoid and relative angular displacement after load application was assessed in an attempt to gauge rotation.¹⁷ This method was incredibly subjective, and the measurements were poorly replicated. Therefore, this portion of the study was abandoned during testing. To properly assess rotation, more precise methods of measurement are necessary.

SBS merits continued clinical studies with long-term follow-up to fully understand its potential uses and complications.

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Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

This article does not contain any studies with human or animal subjects.

Statement of Informed Consent

No individual participants were included in the study.

Declaration of Conflicting Interests

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

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