



Ultrasound localization of lacerated flexor tendon ends in the hand: a cadaveric study

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Abstract

Objective Flexor tendon repair currently requires extensive exposure to locate and repair tendons. Ultrasound (US) has been used to identify lacerated tendon ends with little information on accuracy. This study was designed to measure the accuracy of US to localize tendon ends in zone II flexor tendon lacerations in a cadaveric model.

Materials and methods US was used to locate tendon ends in zone II lacerations of fingers of six cadaveric hands (96 tendon ends) by a musculoskeletal radiologist. The distance of each tendon end relative to the laceration was recorded. Specimens were dissected and tendon position was compared to US position.

Results The radiologist correctly identified full-thickness lacerations of both superficial and deep tendons 99.0% ($n = 05/96$ tendons) of the time. The average difference between mean US predicted retraction and anatomic confirmed retraction for all digits all tendons was 3.5 mm of underestimation. US correctly identified the position of all tendon stumps to within 10 mm 92.7% ($n = 89/96$ tendons) of the time and 69.8% ($n = 67/96$ tendons) of the time to within 5 mm. Error tended to underestimate (61.5%; 59/96 tendons) rather than overestimate retraction (29.2%; 28/96 tendons).

Conclusions This fresh cadaveric study has demonstrated that with an experienced radiologist, there was 99.0% accuracy identifying a completed tendon tear and locating the tendon ends with US to within 1 cm was 92.7% accurate.

Keywords Flexor tendon · Hand ultrasound · Tendon injury · Tendon surgery · Ultrasound

Introduction

Favorable outcomes for zone II flexor tendon laceration repairs remain a challenge. Postoperative stiffness is common and the incidence of reoperation due to adhesions or failure of repair has been reported to be as high as 20% [1]. Currently, surgical techniques involve wide exposures of the finger which may contribute to the postoperative stiffness.

Improving operative technique by minimizing surgical exposure may improve post-operative outcomes.

Ultrasound (US) is a non-invasive, cost-effective, efficient, safe, and readily available imaging modality. Ultrasound was first used to describe hand pathology in 1986 [2], and since then has developed many indications in the evaluation and management of injuries to the flexor tendon apparatus of the hand. Applications include evaluation of the integrity of the flexor

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pulleys [3, 4], quantifying the extent of damage to tendons [5], and identifying failure of repair or the presence of adhesions post operatively [6]. Ultrasound has been previously described as “accurate” in localizing lacerated flexor tendon ends; however, most of these studies consist of case series and do not include measurement of tendon position [7–9]. A study by Ravnic et al. [10] on the accuracy of US in the localization of lacerated flexor tendon ends was able to identify the tendon stumps to within 1 cm 78% of the time using portable equipment. Although their results are encouraging, their findings contradict the high accuracy that is commonly quoted in the literature. Furthermore, better accuracy is needed to achieve consistent results when implementing US to minimally invasive flexor tendon surgery.

We hypothesize that accuracy of predicted tendon end position would be high when sonographically profiled by an experienced radiologist. We created a cadaveric model of a sharp zone II flexor tendon injury of the digit. To assess accuracy, we performed US evaluation of 96 flexor tendon ends and compared the estimated tendon location to its true anatomic retraction.

Methods

Six paired fresh-frozen cadaveric hands from recently deceased donors were prepared and evaluated. Institutional Review Approval was not required for this cadaveric study.

Laceration of digits

To simulate physiologic tensioning of tendons prior to lacerations, a transverse distal forearm incision was used to isolate the flexor digitorum superficialis (FDS) and flexor digitorum profundus (FDP) tendons. PDS 0 looped sutures were placed in the FDS and the FDP tendons and manual force on the sutures was used to apply tension to the tendons; no device was used to apply tension. The skin was covered with ultrasound gel at the time of laceration to avoid entry of air into the laceration. Tension was only applied during division of the tendons.

A surgical scalpel was used to cut the tendons over the proximal phalanx distal to the A2 pulley. Fingers were cut at different degrees of PIP flexion. Index fingers were held in full extension. The long fingers were flexed 30 degrees, the ring finger 60 degrees, and the small finger was flexed 90 degrees, which produced tendon lacerations in various areas along Camper’s chiasm. Complete cuts were the intention at the time of tendon laceration, however, this was not evaluated until the anatomic dissection, performed after the blinded US examination.

US scanning of digits

Ultrasound scans were performed by musculoskeletal trained radiologist with 21 years of musculoskeletal ultrasound

experience (ASS) blinded to the methods used to prepare the cadaveric model. The radiologist was advised that a finger laceration was simulated on each digit and that the purpose of the US evaluation was to quantify the extent of the injury to each flexor tendon (intact, partial, or complete laceration) and identify the position of the tendon ends when retraction was identified. Fingers were placed in a water bath to improve visualization. The fingers were scanned in extension. Flexion was not performed during the US examination, rather, the fingers were only flexed during laceration to produce variability in location. Fingers were scanned and dissected in full extension. A GE Health Care Logiq E9 Ultrasound (Wauwatosa, WI, USA) with an i12L 6–11 MHz hockey-stick probe that had a transducer length of 11.1×34.8 mm was used. Tendons ends were identified in the short and long axis. Full-thickness laceration was defined as the complete discontinuity of fibers on short- and long-axis scan. After each tendon stump was identified on the short axis, the probe was rotated 90 degrees to visualize the tendon’s long axis. The edge of the probe was then aligned with the laceration in the skin so that the edge of the viewing window would coincide with laceration on the skin. The distance between the edge of the viewing window and the tendon stump was measured as the estimated amount of retraction. The procedure was repeated for each lacerated tendon end (Fig. 1).

Anatomical evaluation

After ultrasound evaluation, the skin was then removed from each hand to expose the flexor mechanism. The position of the tendon ends relative to the laceration in the tendon sheath was measured with calipers accurate to 100th of a millimeter and recorded as the actual retraction (Fig. 2a, b).

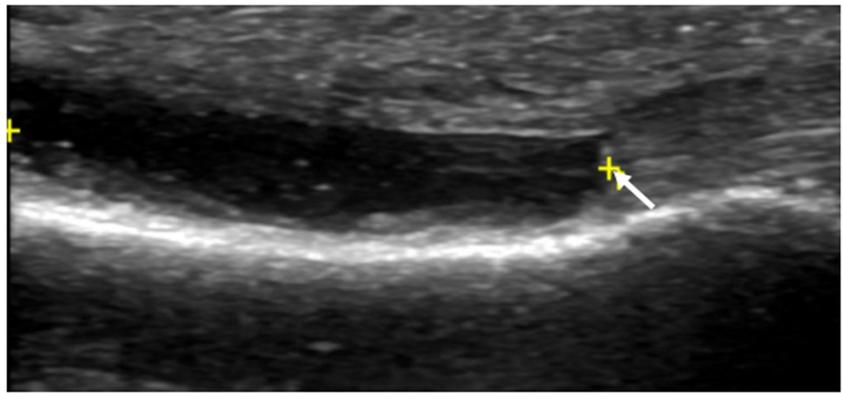
Statistical analysis

Independent group *t* tests were run comparing ultrasound estimated position versus anatomic (true) position of all tendons. The tendon measurement (in mm) is a ratio-level, dependent variable. The independent variable in the study is measurement method, possessing two levels (anatomical and ultrasound). The statistical analysis was repeated after dividing the cohort into sub groups based on finger, tendon type, and proximal/distal stumps. A *p* value of less than 0.05 was considered significant.

Results

The lacerated tendon ends were well visualized in all specimens and all lacerations were complete. US accurately identified 99.0% ($n = 95/96$ tendons) of lacerations as complete lacerations. The mean ultrasound predicted retraction of all

Fig. 1 Long-axis US examination of the retraction FDP (*arrow*) measured to the edge of the viewing window, which corresponds to the level of the skin incision



a



b

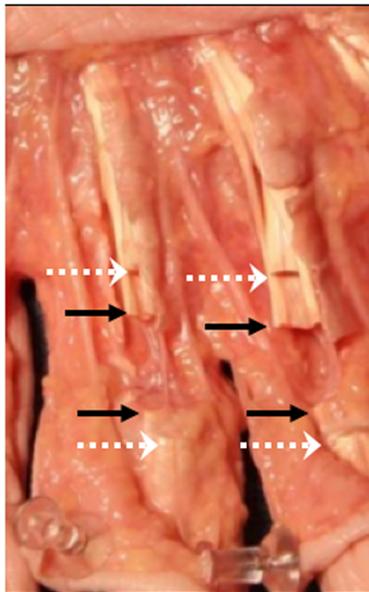


Fig. 2 **a** Anatomic dissection of the palm proximal and distal to laceration exposing the flexor tendon ends. The *dashed box* corresponds to the magnification shown in **b**. **b** Zoomed view of the exposed long and ring fingers, showing the degree of retraction of the FDS (*solid black arrows*) and FDP (*white dashed arrows*)

tendons was 6.4 mm, compared to a mean 9.9 mm true retraction identified on an anatomical dissection. This 3.5-mm underestimation of retraction was statistically significant ($p < 0.0001$ CI 1.8–5.2) indicating a true but clinically small error distance. Stratified analysis of the index and long finger tendon groups did not demonstrate a statistically significant difference between predicted and true tendon position ($p > 0.05$ in all analyses). See Table 1 for details of sub group analysis. Figure 3 depicts confidence intervals for the difference in means (mean error).

We arbitrarily set 10 mm of maximum absolute error of measurement as the limit of what we defined as clinically accurate. Within our data set, 92.7% ($n = 89/96$ tendons) of tendons were within 10 mm of the US predicted position. Accuracy defined in terms of absolute error decreases linearly with stricter tolerances for error. If instead, the threshold for accuracy is changed to an absolute error of less than or equal to 5 mm, the percent of tendons identified within this range falls to 69.8% ($n = 67/96$ tendons) and for a threshold of 3 mm, 42.7% ($n = 41/96$ tendons). Underestimation of retraction was the more common form of error (61.5%; $n = 59/96$ tendons) followed by overestimation 29.2% ($n = 28/96$ tendons) of measurements. 9.4% ($n = 9/96$ tendons) of predicted measurements were exact to the millimeter.

Discussion

This study showed a mean underestimation of 3.5 mm of tendon retraction for all tendons. Specific to our data set, US was accurate to within 1 cm for 93% of our measurements when performed by an experienced radiologist with ultrasound technology. This is an improvement on a similar study performed by Ravnic et al. [11], who reported 78% accuracy within 1 cm by a surgeon without formal US training using an entry level machine. This study demonstrated that US underestimated retraction 61% of the time. This may be due to gapping of the skin edges, making the exact site of the laceration in the tendon sheath difficult for the radiologist to identify.

Table 1 *T* test comparisons between ultrasound and anatomic localization of lacerated cadaveric flexor tendon ends

Independent group <i>t</i> test (ultrasound vs anatomic)		<i>N</i>	Mean	Std. Dev	<i>df</i>	<i>t</i>	Sig (two-tailed)	Mean diff.	L95	U95	Power
All data	US	96	6.36	5.604	190	− 4.136	0	− 3.529	− 5.212	− 1.846	0.984
	Anatomic	96	9.89	6.205							
Index finger tendon ^a	US	24	6.92	7.212	46	− 1.35	0.184	− 3.206	− 7.994	1.581	0.263
	Anatomic	24	10.13	9.13							
Long finger tendon ^a	US	24	5.7	5.904	46	− 1.582	0.12	− 2.338	− 5.311	0.636	0.342
	Anatomic	24	8.04	4.185							
Ring finger tendon	US	24	6.93	5.036	46	− 2.629	0.012	− 3.623	− 6.397	− 0.849	0.732
	Anatomic	24	10.56	4.495							
Small finger tendon	US	24	5.9	4.013	46	− 3.464	0.01	− 4.95	− 7.826	− 2.074	0.924
	Anatomic	24	10.85	5.736							
Tendon end FDS	US	48	6.03	5.601	94	− 3.763	0	− 4.343	− 6.634	− 2.051	0.961
	Anatomic	48	10.37	5.708							
Tendon end FDP	US	48	6.6	5.646	94	− 2.149	0.034	− 2.716	− 5.225	− 0.207	0.595
	Anatomic	48	9.41	6.691							

Negative values for differences reflect underestimation of retraction

^aNo statistical significance between predicted ultrasound position and anatomic but underpowered to reject the null hypothesis

At the time of cadaveric dissection, the degree of FDP retraction and resulting tendon gap after laceration was greater and more pronounced than FDS (Fig. 2b). The distal FDP stumped retracted to the distal edge of the A3 pulley. It appears the circumferential pressure of the intact pulley would squeeze the more mobile FDP proximally while leaving the FDS closer to the site of laceration. This difference in tendon gap did not appear to resolve well on ultrasound visualization, potentially accounting for the difference in error.

The technique used to localize the tendon ends in this study appears susceptible to underestimation error and is limited to tendon retraction less than 3 cm. Nevertheless, it is simple to perform and provide a distance to a reference point that is readily identified. This allows reliable communication between the radiologist and surgeon. When tendon retraction is greater than 3 cm and falls outside of the viewing window, tendon ends can be localized by identifying the tendon in its short axis proximal to its point of retraction and following the

tendon distally until the lacerated end is identified. The probe is then rotated 90 degrees to visualize the tendon in the long axis and centering the tendon end in the middle of the screen. The skin is then marked in line with the middle of the probe at the location of the tendon. This technique offers the advantage of identifying the tendon ends in two dimensions (proximal/distal and radial/ulnar). It does not use the laceration as a reference point and places the structure of interest in the area of the viewing window with the highest resolution. The latter technique potentially offers improved accuracy but relies on marks that may be lost between the time of US evaluation and the time of surgery. One technique we did not employ with the hockey-stick probe with a 2.5-cm footprint is using the extended field-of-view option. Additionally, the ML6-15 probe has a 5-cm footprint and allows for scanning at high frequency (15 MHz) and allows excellent superficial soft tissue delineation. Although the extended field-of-view and the ML6-15 probe, tendons retracting to and past the level of the

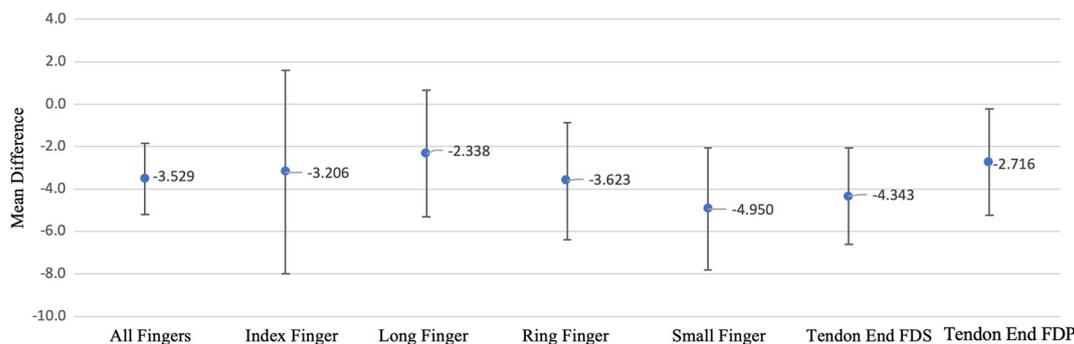


Fig. 3 Differences in average ultrasound predicted position and anatomically confirmed location

metacarpophalangeal joints have substantial angulation, which may not be amenable to a longitudinal sonographic window. Further investigation interrogating these issues is certainly warranted. In any case, the use of ultrasound in pre-operative planning would facilitate minimally invasive tendon retrieval techniques such as those described by Tsuge [11] (Fig. 4). This could translate to decreased operative times and improved functional outcomes.

Ultrasound technology, user expertise, and clinical indications have greatly progressed since Khalegian's description of normal US hand anatomy in 1984 [12]. Although US has been commonly described as accurate for localizing retracted tendon stumps, it has not received widespread implementation in pre-surgical planning. This may be due to a lack of detailed understanding of its true abilities and limitations. To better characterize tendon lacerations with US, it is important to appreciate how tendons respond after laceration. FDS slips follow opposite and complimentary spiral trajectories as they wrap around the FDP in Camper's chiasm; as such, the fibers are not always oriented in the same longitudinal orientation and subsequently are sensitive to US anisotropy. The lacerated proximal superficialis slips have three distinct movements: (i) retract, (ii) flatten out, and (iii) migrate palmarly. The distal superficialis slips also have three movements: (i) migrate distally, (ii) flatten out, and (iii) migrate dorsally. The profundus adopts the contour of the adjacent bony architecture, which may alter the angle of incidence of the tendon fibers related to the amount of retraction. The ultrasound probe should be tilted in the sagittal plane accordingly to compensate for the anisotropy artifact and adequately visualize the tendon end.

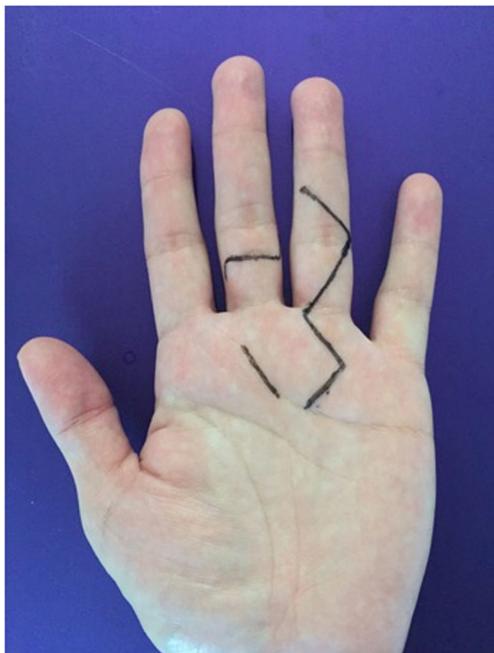


Fig. 4 Minimally invasive incision on the long finger compared to standard Brunner incision on the ring finger

There are several limitations of this study. The lack of inflammatory response and bleeding, in this cadaveric study, may artificially improve the accuracy of US. However, micro-decomposition of the fresh-frozen tissues has been noted to decrease resolution and may in turn decrease accuracy [13, 14]. Additionally, live tendons contract when cut and active contraction of muscles could potentially create a dynamic position of the tendons, which could limit the reliability of radiologist findings at the time of surgery. An additional limitation is that the US was performed by a single experienced musculoskeletal radiologist, so the interobserver error was not explored. A clinical study would be required to look at how increasing time between scan and surgery affects accuracy of the modality. Another limitation is that the specimens all had complete lacerations. Partial lacerations were not evaluated. The distal forearm was dissected to identify a proximal aspect of FDS and FDP tendons and apply tension simulating a contraction. It is unknown if the artificial tension and contraction at this point is similar to a contraction throughout the entire course of the muscle including the tendon of origin. Future studies may aim to dissect more proximally at both the elbow and proximal forearm to apply tension through the entire FDS and FDP muscles. The surgical exposure of the skin and subcutaneous tissue may have contributed to errors in sonographic measurements. Although the release and exposure of the skin, subcutaneous tissue, and tendon sheaths had no visible shift on tendon position during dissection, this was not objectively measured. Certainly, the exposure may have affected the position of the skin incision relative to its normal anatomic configuration. We only used US as an imaging modality; future studies may aim to incorporate high-resolution MR. MR's incorporation and comparison to US measurements would help better delineate if the surgical exposure violated the configuration of the tendons. Additionally, the present study simulated lacerations in an orthogonal fashion at the level of the skin incision. In clinical practice, lacerations may be in any orientation, including oblique orientations that may be difficult to identify relative to tendons' normal orientations. This study had FDS and FDP complete lacerations, whereas in clinical practice, the lacerations may be incomplete or isolated to one tendon group and not the other (e.g., an isolated FDS tear with an intact FDP). The basis of the technique in the present study was to provide sonographic measurements of simulated lacerations with a superficial reference point of the skin incision. We did not profile the absolute tendon gap. While this may be an interesting point in the inherent mechanisms of tendon laceration, the intent in the present study was to identify the lacerated tendon ends relative to a visible superficial landmark (skin incision). This is more clinically relevant to demonstrate the feasibility of identifying the tendon end relative to a clinically evident injury in order for the surgeon to plan their operative approach. Lastly, determining whether regular implementation of ultrasound in the

management of flexor tendon lacerations results in overall improved surgical outcomes cannot be definitively stated without randomized controlled clinical studies.

Tension was only applied during the dissection of the tendon and not applied during the ultrasound examination. Although this introduces variability from the point that the applied manual tension during dissection is released to the subsequent ultrasound examination, such variations in tendon tensions are reflective of lacerations encountered in clinical practice with the interval to surgery, then the varied tensions applied during positioning and repair at the surgical approach and exposure.

In conclusion, the present fresh cadaveric study demonstrated that with an experienced radiologist, there was 99.0% accuracy identifying a completed tendon tear and locating the tendon ends with US to within 1 cm was 92.7% accurate. Improved tendon end localization prior to surgery may decrease operative time, decrease dissection, and improve tendon glide; however, these findings require validation from a future clinical study.

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Compliance with ethical standards

Conflict of interest The authors have no potential conflicts of interest to disclose.

Ethical approval Not applicable.

Informed consent Not applicable.

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