Contact Pressure between Digital Flexors and Plates for Distal Radius Approaches

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Abstract

Background Flexor tendon irritation or rupture following open reduction and volar plate fixation of distal radius fractures can cause significant morbidity and necessitate additional surgical intervention.

Objectives To compare the impact of the extended flexor carpi radialis (e-FCR) and standard flexor carpi radialis (FCR) approaches on contact pressures between the flexor tendons and volar distal radius plates.

Methods Eight matched pairs of fresh frozen cadavers had each limb randomized to undergo either the e-FCR or standard FCR approach. After the approach, a locking plate was applied to the volar distal radius more distally than ideally to create a worst-case scenario for the digital flexor tendons. Electronic pressure sensors were secured to the volar aspect of each locking plate. Each wrist was pinned in 20 degrees of extension during testing. Using a computer-controlled stepper motor system attached to the digital flexor and extensor tendons, the digits were taken through 4,000 cycles simulating 12 weeks of active flexion and extension.

Results There were no statistically or clinically significant differences when comparing the contact pressures of the e-FCR approach with the standard FCR approach at any time intervals. The e-FCR had statistically significantly higher radial-sided contact pressures than ulnar-sided contact pressures during early-to-intermediate testing intervals. These differences resolved at late and final testing intervals.

Conclusions When comparing the standard FCR approach with the e-FCR approach, with the wrist in 20 degrees of extension, there is no significant difference in contact pressures that occur between the digital flexor tendons and volar distal radius plates.

Clinical Relevance Further study and technique modifications may eventually lead to better methods of avoiding flexor tendon rupture during the volar plating of distal radius fractures.

Keywords

- carpal tunnel
- distal radius
- fracture
- tendon rupture
- wrist approach

Distal radius fractures are the most common upper extremity fractures and among the most commonly encountered fractures overall, constituting up to 18% of adult fractures.^{1–3} Currently, caregivers manage these fractures based on a combination of patient requirements, fracture morphology, and personal experience. For fractures treated surgically, authors of randomized studies have demonstrated better short-term functional out-

comes in patients treated with open reduction and internal fixation (ORIF) using volar plating compared with those treated with external fixation or percutaneous pinning.^{4,5} Some authors have also found lower rates of long-term complications and loss of reduction in patients treated with volar plating.⁶

Although ORIF is the most commonly used operative technique for displaced and unstable distal radius fractures,

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surgeons choose their surgical approach and fixation technique based on several factors including comparative reports of complications and outcomes.^{6–14} Of particular concern and interest for volar plating is the known risk of digital flexor tendon rupture.¹⁵ Authors of a recent survey reported that 33% of hand surgeon respondents had encountered at least one flexor tendon injury associated with distal radius volar plating.¹⁶ Investigators report rates of flexor tendon rupture in volar plating as high as 12%, with rupture occurring as late as 10 years after fracture fixation.^{15,17–19} Although the flexor pollicis longus (FPL) is the most commonly ruptured tendon, other digital flexors can also be involved and there have been cases in which additional ruptures have occurred after an initial isolated rupture.^{20,21} Volar plate position and prominence is an independent risk factor for flexor tendon rupture in short-to-intermediate follow-up.¹⁵ More distal plate placement significantly increases digital flexor tendon contact pressure with the plate and is likely the mechanism by which flexor tendon injury occurs.¹⁹ However, sometimes, distal radius fracture characteristics require the plate to be placed more distally than what is considered ideal. In these cases, surgeons often recommend to have the plate removed once the fractures are healed.

Although most surgeons use a flexor carpi radialis (FCR) approach to the palmar distal radius, an extended FCR (e-FCR) approach allows for concurrent carpal tunnel release through the same incision.^{22,23} In the e-FCR approach, the transverse carpal ligament (TCL) is released radially in the interval between the FPL and the FCR adjacent to where the superficial and deep leaves of the TCL surround the FCR. Once this is released, there is no longer a volar restraint to the contents of the carpal tunnel, and with this approach, the digital flexor tendons, especially the FPL, shift palmarly.^{22,24} In our experience from postoperative explorations for other indications, the release from the e-FCR approach can even result in the FPL resting palmar to the FCR. Thus, with this approach, the digital flexor tendons may have less contact pressure with the volar distal radius and any hardware present, and there may be a lower risk of tendon irritation or rupture. Recent studies have shown no short-term increased risk of postoperative carpal tunnel syndrome or tendon ruptures using this e-FCR approach.^{24,25}

For this study, we sought to investigate the impact of the e-FCR approach on contact pressures that occur between the digital flexor tendons and volar distal radius plates in a cadaveric model. We hypothesized that compared with a standard FCR approach, an e-FCR approach would result in decreased contact pressures during simulated active digital range of motion.

Methods

Sixteen fresh frozen cadaveric upper extremities, consisting of eight matched pairs, with absent radiographic findings of prior injury or surgery were used for the study. The specimens were disarticulated at the elbow. One specimen from each matched pair was randomized to undergo a standard FCR approach to the distal radius, whereas the contralateral specimen underwent an e-FCR approach.

Fig. 1 (A) Skin incision using the standard flexor carpi radialis (FCR) approach. (B) Demonstration of a locking plate applied through the standard FCR approach.

In the standard FCR approach, we made a longitudinal skin incision in line with the FCR tendon ending distally at the distal-most volar wrist crease (→ **Fig. 1**). We incised the superficial FCR tendon sheath in line with the skin incision and retracted the FCR tendon to expose the floor of the FCR tendon sheath. We sharply incised the deep FCR tendon sheath and retracted the FPL ulnarly. We excised the pronator quadratus muscle. We applied a 2.4-mm stainless steel volar distal radius locking plate (DePuy Synthes, West Chester, PA) with the distal end positioned distal to the watershed line to simulate Soong grade 2 placement as a worst-case scenario for the digital flexor tendons.¹⁵ We confirmed plate placement fluoroscopically as well. We placed just enough distal and proximal screws to secure the plate to the radius.

In the e-FCR approach, we made a longitudinal skin incision in line with the FCR tendon to the scaphoid tubercle (→ **Fig. 2**). At the level of the distal volar wrist crease, we angled the incision radially toward the base of the thumb and extended the incision 1 to 2 cm distally from the wrist crease.²³ We incised the superficial and deep portions of the FCR tendon sheath in line with the skin incision and mobilized the FCR radially. Distally, we split the thenar musculature in line with the skin incision. We excised the pronator quadratus muscle. We identified the FPL and sharply divided the interval between the FPL and FCR. Distally, this included using a tenotomy scissors under direct visualization to sharply divide first the superficial leaf and then the deep leaf of the TCL. We confirmed complete release of the TCL and decompression of the carpal canal by direct visualization and palpation. We then applied the same size and type of distal radius plate using the same technique and position as for the standard FCR approach.

For each specimen, we identified the long finger flexors proximally and separately sutured the tendons of the flexor digitorum superficialis (FDS) together and those of the flexor digitorum profundus (FDP) together (→ **Fig. 3**). We also placed a proximal suture in each FPL tendon. Three electronic pressure sensors (Tekscan 6911 pressure sensors, Tekscan, Boston,

Fig. 2 Skin incision for extended flexor carpi radialis approach.

MA) were secured on the radial, central, and ulnar aspects of each distal radius plate (►Fig. 4) after calibration with an equilibrator bladder (Tekscan) per manufacturer recommendations. The skin was closed with 3-0 nylon suture in a running fashion. Dorsally, we made an incision in the proximal forearm, identified the tendons of the extensor digitorum communis and extensor pollicis longus, and sutured all of these together. We closed the skin with 3-0 nylon suture in a running fashion.

We mounted each wrist on a testing frame and pinned each wrist in 20 degrees of extension with a 0.062" smooth Kirschner wire extending from the distal ulna into the carpus (►Fig. 5). This position simulates a functional postoperative wrist position to facilitate early digital range of motion following volar distal radius plate fixation. This also allowed us to maintain a constant wrist extension position while the digital flexors and extensors were being loaded and cycled. Other investigators studying changes in contact pressures about the distal volar radius have also used positions similar to this.¹⁹ Using a computer-controlled stepper motor system (Kollmorgan Corporation, Radford, VA) and a 111N load cell, MLP-25, (Transducer Techniques, Temecula, CA), the digital flexors and extensors were cyclically loaded through 4,000 cycles to approximate 12 weeks of digital flexion and extension using a closed-loop algorithm (LabVIEW, National Instruments,

Austin, TX).²⁶ The mean contact pressures between the digital flexor tendons and the distal radius plate were measured for each specimen in the two groups at predetermined cycle intervals, which included 10, 100, 1,000, 2,000, 3,000, and 4,000 cycles.

We used paired *t*-tests to compare the mean differences in contact pressures between the FCR and e-FCR exposures at each predetermined cyclic time point. Statistical significance was set at $p = 0.05$. We used repeated measures two-way analysis of variance (ANOVA) to determine any significant differences in contact pressures when considering FCR versus e-FCR exposure and radial versus ulnar pressure sensor location. After completion of 4,000 cycles, the tendons were also visually inspected for any apparent morphological changes. Based on prior literature, notably studies by Soong et al and Tanaka et al, we assumed that a contact pressure difference of 25% would likely correlate with a clinically significant outcome.^{15,19} After completion of initial testing, we performed a posthoc power analysis.

Results

Radial-sided contact pressures: there were no statistically or clinically significant differences for mean radial-sided contact pressures between the standard and e-FCR approaches at any time points (►Fig. 6).

Central contact pressures: there were no statistically or clinically significant differences for the mean central contact pressures between the standard and e-FCR approaches at any time points (►Fig. 7).

Ulnar-sided contact pressures: there were no statistically or clinically significant differences for the mean ulnar-sided contact pressures between the standard and e-FCR approaches at any time points (►Fig. 8). For the e-FCR approach, the mean ulnar-sided contact pressures were significantly lower than the radial-sided pressures at the early and intermediate time points but became insignificant at the later and final time points (►Fig. 9). When comparing radial- versus ulnar-sided contact pressures for e-FCR versus standard FCR using ANOVA, there was no significant difference.

Discussion

Surgeons have recently favored using a volar approach and plating for the management of operative distal radius fractures

Fig. 3 (A) Sutured flexor tendons and (B) extensor tendons.

Fig. 4 Electronic pressure sensors secured to a volar plate in the (A) standard and (B) extended flexor carpi radialis approaches.

Fig. 5 (A) The wrist mounted in extension with subcutaneously tunneled sutures proximally connected to a computer-controlled stepper motor system and (B) demonstrating flexion during a cycle.

Fig. 7 Mean pressure measured (in kPa) at each time point for the central sensor over the volar plate in both the extended flexor carpi radialis (FCR) and standard FCR approaches.

Fig. 6 Mean pressure (in kPa) at each time point for the radial sensor over the volar plate in both the extended flexor carpi radialis (FCR) and standard FCR approaches.

Fig. 8 Mean pressure measured (in kPa) at each time point for the ulnar sensor over the volar plate in both the extended flexor carpi radialis (FCR) and standard FCR approaches.

Fig. 9 Comparison of radial- and ulnar-sided sensor pressure means (in kPa) at each time point in the extended flexor carpi radialis approach.

because of perceived procedural advantages, biomechanical benefits, and lower reoperation rates.^{14,19,27,28} Flexor tendon rupture has become an increasingly reported complication of volar plating.^{5,7,8,16,19} In limited studies, the e-FCR approach appears to have lower rates of neuropathy and carpal tunnel syndrome compared with reports of other approaches, although appropriately powered direct comparisons are lacking. There have been no reports of flexor tendon injury or rupture in these series, possibly secondary to the concurrent carpal tunnel release and greater excursion of the flexor tendons with this approach.^{24,25} Prior studies have shown both an association between plate position and flexor tendon rupture²⁹ and an association between plate position and flexor tendon contact pressures.¹⁵ Increased contact pressure may be the mechanism by which flexor tendons rupture as a result of plate placement. Certainly, these associations as well as current surgical observations are consistent with the concept that the tendons must be directly contacting the plate to lead to attritional changes and eventual rupture when it does occur.

Given the relatively low rate of actual flexor tendon rupture following volar distal radius plating, these studies are underpowered to demonstrate statistically significant differences between approaches. Our purpose was to provide a more thorough understanding of the e-FCR approach's impact on contact pressures at the interface of the digital flexor tendons and volar distal radius plates.

We found no statistically significant differences in the contact pressures between the standard and e-FCR approaches when measured on the radial, central, or ulnar portions of the volar plate. Looking exclusively at the e-FCR approach, we found that the radial-sided contact pressures were significantly higher than the ulnar-sided pressures at early and intermediate time points (100–2,000 cycles). This early increase in radial-sided contact pressures could be secondary to the release of the radial side of the carpal tunnel, which allows for radial translation of the digital flexor tendons and likely impacts contact pressures on the volar plate. The fact that this difference resolved after 2,000 cycles, which approximates to a 6-week time point, makes the clinical significance of this less concern-

ing. This may warrant further study considering that the FPL is the most radial flexor tendon at this level. We found no differences between pressure recordings for the e-FCR approach at the final 4000-cycle point, which simulates a 12-week postoperative time point.

In the series reported by Tannan et al, 27 patients underwent either e-FCR approach or what they described as a traditional volar Henry approach for distal radius fractures.²⁴ At 6 and 12 weeks, there were no significant differences in subjective scores and objective examination between the two approaches and there were no reports of neuropathy, carpal tunnel syndrome, or flexor tendon ruptures at the final reported follow-up of 3 months. While it is possible that their study did not yet allow for a sufficient follow-up period to identify cases of flexor tendon irritation or rupture, FPL rupture has been reported to occur as early as 12 weeks postoperatively.²⁰ A retrospective review by Gwathmey et al investigated complications in 65 patients following e-FCR approach for distal radius fracture fixation at an average follow-up of 30 months. They similarly had no cases of flexor tendon injury or rupture.³⁰ Presently, we are unaware of any cases in which a flexor tendon rupture occurred after the e-FCR approach at our institution or in the literature.

In a similar study to ours, Tanaka et al investigated the contact pressures between the FPL and a volar distal radius plate. They found the pressure was significantly increased with plate placement distal to the watershed line when the wrist was at 30 degrees and 60 degrees of extension.^{15,19} However, Tanaka et al measured only the contact pressure between the FPL and the plate. They also resected the FDS and FDP, which significantly differs from normal clinical conditions and did not allow inclusion of these clinically relevant tendons during pressure measurements. Additionally, they did not include measurement of the pressures from radial to ulnar along the distal portion of the plate.¹⁹ In our study, we employed three sensors that completely covered the distal portion of the plate and allowed for a more accurate assessment of contact pressures. This allowed us to search for any significant pressure changes for all of the digital flexor tendons and also to identify significant early differences between the pressures on the ulnar and radial aspects of the plate in the e-FCR approach.

Our study has several limitations. First, contact pressure measurements and procedures were performed on cadaveric specimens. Although cadaveric specimens have been used for similar studies,¹⁹ it is unclear whether different results would be obtained in clinical practice. This is pertinent in the postoperative setting due to the inherent differences in living versus nonliving tissue, most notably that soft tissue swelling may have an impact on contact pressures. In addition, our study may have been underpowered to determine if any true differences exist between these surgical approaches with regard to flexor tendon and distal radius plate contact pressures. Posthoc sample size calculations based on our results indicated that to demonstrate a statistically significant difference between the two approaches, in excess of 100 cadaveric matched pairs would be required. We therefore decided that it is unlikely that there are clinically significant differences in

flexor tendon contact pressures between the standard and e-FCR approaches with this model and did not pursue further testing. It is also possible that with greater degrees of wrist flexion or extension, we would see different results. Finally, the placement of the distal radius volar plate in our study was past the watershed line as we intended to reproduce the highest-risk position for flexor tendon rupture and, theoretically, tendon-plate contact pressures. This placement is not routine clinical practice and is only used whenever adequate fixation is necessary to obtain.¹⁵ In this way, we sought to determine whether one approach to the distal radius was potentially more protective than the other in this worst-case scenario.

We hypothesized that the e-FCR approach would result in decreased contact pressures at the interface of the flexor tendons and volar distal radius plate, but this was not observed in our cadaveric model with the wrist in 20 degrees of extension. Future biomechanical or clinical investigations may eventually determine methods to protect the digital flexor tendons following volar distal radius plating, especially in these highest-risk positions.

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Conflict of Interest

None declared.

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