SCIENTIFIC ARTICLE

Flexor Pollicis Longus Dysfunction After Volar Plate Fixation of Distal Radius Fractures

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Purpose To evaluate the natural history and etiology of decreased thumb interphalangeal (IP) joint flexion after volar plate fixation of distal radius fractures.

Methods A total of 46 patients who underwent volar plating of 48 distal radius fractures by a single surgeon were retrospectively studied. Of those patients, 24 (24 wrists) exhibited loss of thumb IP joint flexion (group 1) and 22 (24 wrists) retained thumb IP joint flexion (group 2) with attempted thumb opposition to the small finger after surgery. All patients were seen at regular intervals until IP joint flexion returned and fracture healing was confirmed radiographically. Patient demographics, fracture patterns, surgical variables, and final radiographs were compared between groups. Twenty patients in group 1 were seen after a mean of 6.5 months (range, 5–12 mo) for specific outcome measurements. Eight cadaveric specimens were used to replicate the flexor carpi radialis approach to the distal radius and evaluate flexor pollicis longus tendon excursion.

Results There were no significant differences in fracture pattern, patient age or sex, injured extremity dominance, time to surgery, incision length, plate composition, plate length, tourniquet time, or final wrist radiographs between groups. In group 1, active thumb IP joint flexion returned on average 52 days (range, 19–143 d) postoperatively. At final evaluation in this group, mean IP joint flexion was 11° less than the contralateral thumb IP joint; however, patient-determined outcomes were favorable in most cases. In the cadaveric specimens, excursion of the flexor pollicis longus tendon decreased with sequential soft tissue dissection and retraction.

Conclusions Loss of thumb IP joint flexion after volar plating of distal radius fractures was common, and motion returned to near normal in most cases within 2 months. Partial stripping of the flexor pollicis longus muscle from investing fascia and bone and retraction of soft tissues are likely etiological factors. *(J Hand Surg 2013;38A:1691–1697. Copyright © 2013 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Prognostic III.

Key words Complications, distal radius fracture, flexor pollicis longus injury, volar plate fixation, wrist fracture.

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A well-established surgical approach to the repair of distal radius fractures is through the flexor carpi radialis (FCR) sheath. The dissection necessitates separation of fascia investing the distal portion of the flexor pollicis longus (FPL) muscle, retraction of both the FCR and FPL muscle–tendon units, and variable elevation of the distal FPL muscle attachment from the radius.[1]

Loss of FPL function after plating of mid and proximal radial shaft fractures has been reported and is postulated to be the result of anterior interosseous nerve injury.[2] More recently, disruption of the FPL tendon after volar plate fixation of distal radius fractures has been recognized and attributed to implant prominence.[3–8] The senior author (D.M.K.) and his colleagues have noticed frequent and temporary loss of normal thumb interphalangeal (IP) joint flexion after volar plate fixation of distal radius fractures through the FCR exposure.

The purposes of this study were to assess the natural history of poor thumb IP joint flexion after volar plating of distal radius fractures and to investigate the etiology of this phenomenon clinically and in a cadaveric model. We hypothesized that stripping of a portion of the FPL investing fascia, distal elevation of the muscle origin from bone, and temporary retraction of the soft tissues may alter the normal length–tension relationship of the FPL muscle–tendon unit.

MATERIALS AND METHODS

Study population

After obtaining institutional review board approval, we reviewed the records of 48 consecutive adult patients (50 wrists) who underwent volar plating of a displaced distal radius fracture(s) by the senior author between January 2010 and October 2011. Beginning in January 2010, the senior author maintained a prospective record of all patients who exhibited loss of thumb IP joint flexion with attempted opposition to the little finger at the first postoperative evaluation. These patients had normal thenar muscle tone and demonstrated IP joint flexion with attempted thumb opposition before surgery. Thenar muscle tone was preserved, and active flexion and extension of the IP joint with the thumb ray passively extended and radially abducted were demonstrated after surgery.

Two patients who had previously undergone fracture repair surgery on the same wrist were excluded. The final retrospective cohort study consisted of 24 patients (24 wrists) who exhibited loss of thumb IP joint flexion (group 1), and 22 patients (24 wrists) who retained thumb IP joint flexion (group 2) with attempted opposition to the little finger base at the first postoperative visit. There were 18 women and 6 men with an average age of 57 years (range, 21–83 y) in group 1. The dominant extremity was involved in 16 of 24 (67%) cases, and the time to surgery averaged 12 days (range, 4–43 d). In group 2, there were 16 women and 6 men with an average age of 48 years (range, 25–82 y). The dominant extremity was injured in 10 of 24 cases (42%), and the time to surgery averaged 19 days (range, 1–50 d).

Surgical technique and postoperative care

A longitudinal skin incision was made over the FCR tendon, fascia investing the FCR tendon was opened, and the FCR and FPL tendons were retracted ulnarward, necessitating stripping of a relatively small region of fascia covering the volar-radial margin of the distal FPL muscle. The mean incision length in both patient groups measured 5.5 cm (range, 2.5–8.0 cm). The pronator quadratus was elevated subperiosteally in an ulnar direction, the brachioradialis tendon was released from the radial styloid, and the distal origin of the FPL muscle on the radius was elevated subperiosteally for a short distance to accommodate the implant. Finger traps were placed over the index and middle fingers and 2.3 to 4.5 kg of retraction was applied temporarily to assist with fracture reduction. We used a hand-holding device, a self-retaining wound retractor, and Army-Navy retractors throughout the procedure.

A titanium volar locking plate (DVR; Hand Innovations, Miami, FL) was inserted in 14 group 1 and 18 group 2 cases. A stainless-steel volar locking plate (TriMed, Santa Clarita, CA) was implanted in 8 group 1 and 6 group 2 cases. In 2 patients from group 1, we used a stainless-steel volar buttress plate (TriMed) instead of a volar locking plate. The mean plate length in group 1 patients measured 4.8 cm (range, 4.3–5.2 cm), and the mean plate length in group 2 patients measured 5.0 cm (range, 4.7–6.0 cm). Both buttress plates measured 4.3 cm in length and the width of the proximal limb in all implant designs ranged from 9 to 11 mm.

The volar locking plates and 1 buttress plate were positioned in-line or proximal to the watershed line, as confirmed by intraoperative inspection and fluoroscopic imaging, whereas the distal end of the other volar buttress plate was purposely placed beneath the volar lip of the distal radius. The distal limb of the locking plate was elevated slightly from bone in 6 cases (3 cases in each patient group). The pronator quadratus was reapproximated loosely over the plate with absorbable sutures, the skin was closed with absorbable and nonabsorbable sutures, and the wrist was immobilized in a

TABLE 1. AO Classification of Wrist Fractures

AO Type	Group 1 (n = 24)	Group 2 (n = 24)
A1, A2, A3	7	6
B2, B2, B3	8	11
C1, C2, C3	9	7

volar plaster splint. An upper arm tourniquet was inflated for an average of 88 minutes (range, 46–128 min) in group 1, and for an average of 89 minutes (range, 43–127 min) in group 2.

The treating surgeon and an occupational therapist saw all patients at weekly intervals for the first 3 to 4 weeks, every other week for the next 2 to 4 weeks, and then every 4 to 6 weeks until thumb IP joint flexion returned, defined by the presence of thumb tip opposition to the middle or proximal one third of the little finger, and radiographic fracture consolidation. Occupational therapists serve as physician extenders in the senior author's practice. Immediate active and passive digital motion exercises were encouraged, whereas the wrist was immobilized for 6 weeks. Wrist radiographs were obtained within the first week after surgery and at varied intervals during the course of treatment. A musculoskeletal radiologist and a neurologist, respectively, completed dynamic ultrasound and electromyography studies of the FPL muscle–tendon unit in 2 patients in group 1 between 3 and 4 weeks postoperatively.

Radiographic classification and measurements

Two investigators reviewed the initial injury and latest follow-up wrist radiographs in each case and a consensus was reached for the AO fracture classification (Table 1) and bone healing. The same two investigators made independent measurements of distal radial morphology on the final wrist images using digitized images, and included radial inclination, sagittal alignment, and ulnar variance (Table 2). The means of these measurements were calculated for later analysis.

Group 1

Of the 24 patients in group 1, 20 (83%) agreed to return specifically for this study at an average of 6.5 months (range, 5–12 mo) after surgery. We obtained informed consent from each of these patients. An occupational therapist completed outcome assessment, which included the Quick–Disabilities of the Arm, Shoulder and Hand (QuickDASH) questionnaire; a visual analog scale of patient satisfaction; measurements of forearm, wrist, and thumb motion; and measurements of grip and key pinch (Table 3). New standard radiographic views of the injured and contralateral wrists were completed.

The QuickDASH questionnaire includes 11 items that gauge symptoms and function applicable to upper extremity musculoskeletal disorders. The score is based on a scale of 0 to 100 points, with a lower score reflective of a better outcome. The visual analog scale includes numeric responses on a scale from 0 to 10, with 0 representing very satisfied and 10 representing not satisfied. Active joint motion measurements were obtained without stabilization of adjacent joints using a handheld goniometer. Grip and pinch strength measurements were completed using a dynamometer and a key pinch device (Sammons Preston, Inc., Bolingbrook, IL). The dynamometer was set at position 2, and the averages of 3 measurements were recorded for grip and key pinch.

Cadaveric study

For 8 above-elbow fresh-frozen arm specimens, the average age of the 4 male and 4 female specimens was 65 years (range, 60–75 y). The limbs were stored at −40°C and thawed at room temperature for approximately 24 hours before dissection.

We used 2 4.5-mm threaded Steinmann pins to stabilize the wrist in neutral alignment. We drilled 4 additional 4.5-mm threaded Steinman pins into the radial and ulnar shafts, taking care not to entrap the flexor and extensor muscle–tendon units. Each shaft pin was then secured to a custom sleeve that was attached to a vertical magnetic post on a flat metal platform (Fig. 1).

An eyelet screw was seated into the thumb distal phalanx to control thumb positioning. The thumb was secured in maximum extension and radial abduction to simulate the intraoperative placement of the thumb in a hand-holding device. A 6-cm longitudinal skin incision was then made over the FPL muscle, extending proximally from a point approximately 12 cm proximal to the radiocarpal interval. We performed careful soft tissue dissection and identified the FPL musculotendinous junction. A tag suture was placed in the FPL tendon and aligned with the tip of a pin attached to a magnetic post.

The thumb was repositioned into maximum flexion and adduction, and a caliper was used to measure the distance from the tag suture in the FPL tendon to the tip of the fixed pin, reflecting the distance of FPL tendon excursion (Table 4). An 8-cm longitudinal skin incision was then made over the FCR tendon distally to simulate the FCR approach to the distal radius. A 3- to 4-cm bridge of soft tissue was preserved between the 2 forearm exposures.

TABLE 2. Final Distal Radius Fracture Alignment

Radiographic Measurement	Group 1 (n = 24)	Group 2 (n = 24)	*P* Value
Mean radial inclination, degrees	22 ± 4 (18–30)	23 ± 6 (11–38)	.59
Mean volar tilt, degrees	5 ± 5 (−3 to 14)	5 ± 5 (−11 to 12)	.72
Mean ulnar variance, mm	−0.1 ± 0.3 (−0.6 to 0.6)	−0.2 ± 0.3 (−0.5 to 0.5)	.22

Two independent observers completed measurements. Data are presented as means, standard deviations, and ranges; angle measurements are rounded to the nearest whole numbers.

TABLE 3. Group 1, Joint Motion and Strength Measurements

Measurements	Injured Wrist	Uninjured Wrist	*P* Value
Supination, degrees	73 ± 7 (60–85)	81 ± 6 (70–90)	< .01*
Pronation, degrees	78 ± 7 (60–90)	82 ± 8 (75–90)	< .05
Wrist extension, degrees	60 ± 7 (48–70)	71 ± 8 (55–85)	< .01*
Wrist flexion, degrees	53 ± 10 (43–68)	71 ± 9 (55–80)	< .01*
Wrist radial deviation, degrees	20 ± 6 (10–37)	26 ± 6 (20–35)	< .01*
Wrist ulnar deviation, degrees	27 ± 7 (15–45)	35 ± 5 (25–45)	< .01*
Thumb CMC radial abduction, degrees	46 ± 9 (25–60)	51 ± 10 (35–70)	.01
Thumb CMC palmar abduction, degrees	47 ± 9 (30–60)	49 ± 9 (35–62)	.04
Thumb MCP joint arc, degrees	52 ± 14 (33–85)	56 ± 13 (25–73)	.15
Thumb IP joint arc, degrees	69 ± 16 (50–95)	80 ± 22 (50–115)	< .01
Hand grip, kg	19.5 ± 9.5 (2.3–38.6)	26.4 ± 9.5 (10.0–52.3)	< .01*
Key pinch, kg	5.9 ± 2.3 (2.3–10.9)	6.8 ± 2.3 (3.2–13.6)	< .01

Data are presented as means, standard deviations, and ranges; measurements are rounded to the nearest whole numbers.
CMC, carpometacarpal; MCP, metacarpophalangeal; IP, interphalangeal.
*$P < .0001$.

The thumb was repositioned into maximum extension and radial abduction before each subsequent step in the approach. We assessed excursion of the FPL tendon by passively moving the thumb into maximum flexion and adduction and measuring the distance between the tag suture in the FPL tendon and the fixed pin tip. After fully exposing the distal radius, the FCR tendon and the contents of the carpal tunnel were retracted in an ulnar direction using an Army-Navy retractor with a mean force of 2.3 kg for 5 minutes (a typical retraction force of 2–3 kg was measured *in vivo*). Excursion of the FPL tendon was again quantified.

The FPL muscle origin distally on the radius was subsequently released in a distal to proximal direction at 1-cm increments over a distance of 6 cm, and excursion measurements of the FPL tendon were completed. (A 6-cm release of the distal FPL muscle from bone is equivalent to detaching the muscle for a distance of approximately 3 cm proximal to a 5-cm-long volar plate.) After 6 cm of muscle detachment, the FCR tendon and the contents of the carpal tunnel were again retracted in an ulnar direction with a mean force of 2.4 kg for 5 minutes and excursion of the FPL tendon was measured. Finally, the forearm was dissected to quantify the FPL muscle footprint on the radial shaft and assess for the presence of a Gantzer muscle and interconnections between the FPL and index finger flexor digitorum profundus tendons.

Statistical methods

We calculated descriptive statistics for all variables of interest. An adjustment for hand dominance was not performed. We summarized continuous measures with use of means, standard deviations, and ranges; we summarized categorical measures with use of counts and percentages. Two sample independent *t*-tests were used to compare patient ages, days to surgery, incision lengths, tourniquet times, and radiographic measurements of final fracture alignment between the dysfunc-

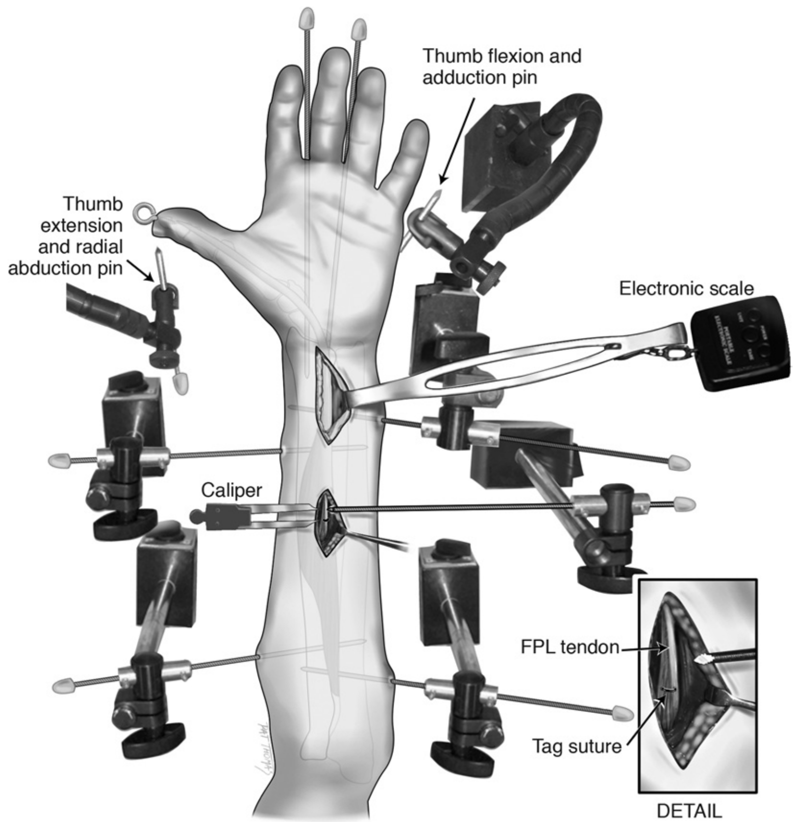

FIGURE 1: Illustration of the testing jig with a mounted specimen.

TABLE 4. Flexor Carpi Radialis Approach to Distal Radius

Procedural Step (8 Specimens)	FPL Tendon Excursion, mm	*P* Value
Exposure for tag suture	8 ± 4 (4–16)	NA
Incision skin and fascia investing flexor carpi radialis	6 ± 2 (4–9)	.13
Incision fascia along radial margin flexor pollicis longus	6 ± 2 (4–8)	.03
Elevation pronator quadratus and release brachioradialis	5 ± 2 (3–8)	.01
5 min retraction with 2.3 kg force	3 ± 1 (2–5)	.01
Elevation distal FPL		
1 cm	4 ± 2 (2–9)	.01
2 cm	4 ± 2 (2–9)	.01
3 cm	3 ± 2 (2–9)	.01
4 cm	3 ± 2 (2–9)	.01
5 cm	3 ± 2 (2–9)	.01
6 cm	3 ± 2 (2–9)	.01
5 min retraction with 2.4 kg force	2 ± 1 (1–5)	.01

Data are presented as means, standard deviations, and ranges; excursion measurements are rounded to the nearest millimeter.
NA, not applicable.

tional and intact thumb IP joint flexion groups. We used the Wilcoxon rank sum test to compare the lengths of plates between groups. Fisher's exact test was used to evaluate the relationship between the presence of FPL dysfunction and categorical variables, including AO fracture classification, sex, injured extremity dominance, and plate composition. Paired *t*-tests were used to compare the means of joint motion and strength measurements between injured and uninjured wrists and the effects of sequential soft tissue dissection and retraction on FPL excursion. A significant difference was defined as $P < .05$.

RESULTS

All patients

The fracture patterns using the AO classification were similar between group 1 and group 2 cases ($P = .76$). There were no significant differences in patient age or sex, dominance of the injured extremity, time to surgery, incision length, plate composition, plate length, tourniquet time, or final distal radial alignment between groups. All fractures united, and no additional wrist surgical procedures were performed during the study period.

Group 1

Dynamic ultrasound and electromyography of the FPL muscle–tendon unit in 2 patients with dysfunctional IP joint flexion revealed normal findings. In all cases, active flexion of the thumb tip to the middle or proximal one third of the little finger returned on average 52 days (range, 19–143 d) postoperatively, 17 of 24 patients (71%) within 2 months. At the final assessment, active motion of the affected thumb IP joint averaged 11° less than the contralateral thumb IP joint ($P < .05$). Active motion of the forearm, wrist, and thumb carpometacarpal joint and grip and key pinch strength measurements were also less on the injured side ($P < .05$). The mean QuickDASH score was 14 (range, 2–61), and the visual analog satisfaction scale averaged 1.6 (range, 0–7.8).

Cadaveric study

Incision of the fascia investing the FCR tendon resulted in an insignificant decrease in FPL tendon excursion ($P = .13$). All subsequent steps in exposure of the distal radius resulted in statistically significant decreases in FPL tendon excursion ($P < .05$). Excursion of the FPL tendon decreased from an average of 6 ± 2 mm to an average of 2 ± 1 mm with sequential soft tissue dissection and retraction.

The mean length of the FPL muscle footprint on the radial shaft measured 165 mm (range, 145–185 mm), and the mean width of the muscle footprint on bone measured 19 mm (range, 15–23 mm). The proximal margin of the FPL muscle averaged 35 mm (range, 15–23 mm) distal to the proximal surface of the radial head, and the distal margin of the muscle averaged 31 mm (range, 24–37 mm) proximal to the tip of the radial styloid.

A 6-cm-long dissection of the distal FPL muscle from the radial shaft averaged 36% of the longitudinal bony footprint. A Gantzer muscle was present in 4 of 8 cadaveric limbs, whereas anomalous interconnections between the FPL and index flexor digitorum profundus tendons were not detected.

DISCUSSION

We observed temporary loss of thumb IP flexion in one half of 48 consecutive surgical cases by a single surgeon using a consistent surgical approach. Most patients regained active thumb flexion to the middle or proximal one third of the little finger within 2 months after surgery, and all patients regained this motion by 5 months.

Scar entrapment of the FPL tendon, hardware irritation and impingement, and neuropraxia of the anterior interosseous nerve are recognized causes of FPL dysfunction.[2,4,9] Placement of a volar locking plate distal to the watershed line of the distal radius and excessive plate prominence have been associated with FPL tendon rupture.[8,10,11] All but 1 of the volar implants in our series was positioned in-line or proximal to the watershed line. The distal limb of the plate was slightly elevated from bone in 6 cases, but with a comparable number of prominent implants in each patient group. There were no clinical cases of FPL tendon disruption, and early dynamic ultrasound studies in 2 cases with FPL dysfunction showed no impediment to tendon excursion.

Previous studies have found 1 to 6 branches of the anterior interosseous nerve entering the FPL muscle on the proximal-medial side.[2,12–14] We doubt that FPL muscle innervation was compromised by our surgical technique, which included a limited release of distal investing fascia, subperiosteal elevation of the distal muscle origin from bone, and retraction of soft tissues toward the midline of the forearm. Subperiosteal dissection and medial retraction of the FPL muscle decrease tension on the anterior interosseous nerve.[2,13] Postoperatively, active flexion of the thumb IP joint with the ray passively extended and radially abducted was preserved in all group 1 patients. In addition, electromyography studies of the FPL muscle in 2 cases with FPL dysfunction revealed normal findings between 3 and 4 weeks after surgery. For the sake of economy, we did not order ultrasound or electrodiagnostic studies for other patients.

Fracture pattern, patient age and sex, extremity involvement, time to surgery, incision length, plate composition, plate length, tourniquet time, and final distal radial alignment did not appear to affect thumb IP joint flexion postoperatively. The findings from our cadaveric experiment suggested that elongation of the FPL muscle–tendon unit from soft tissue dissection and wound retraction in the FCR exposure to the distal radius will lead to diminished tendon excursion. Limited subperiosteal stripping of the FPL muscle to accommodate a standard-size volar plate may release up to one third of the distal bony origin. In addition, use of an intraoperative hand-holding device with the thumb held in extension and retropulsion may place undue tension on the FPL tendon. As a result, a temporary altered functional length over which the FPL muscle must operate may limit full flexion of the thumb IP joint.

Previous cadaveric studies have shown that a Gantzer muscle is present in 52% to 74% of the time, and interconnections between the FPL and index flexor digitorum profundus tendons (Linburg Comstock anomaly) are present in approximately 25% of forearms.[15–17] Disruption of a Gantzer muscle and/or a Linburg Comstock anomaly may conceivably impair normal active thumb IP joint flexion. A Gantzer muscle was present in 4 of 8 cadaveric limbs in our study; nevertheless, we measured decreased tendon excursion in all 8 specimens with sequential steps in the exposure and soft tissue retraction. We did not detect anomalous interconnections between the FPL and index finger flexor digitorum tendons.

We recognize several limitations of our study. Interobserver and intraobserver variability may have influenced the initial injury classifications and final radiographic measurements. In all cases, active thumb IP joint flexion was observed but not quantified before and early after surgery; consequently, we were unable to determine whether differing IP joint flexion deficits existed before surgery and were associated with the development of differing IP joint flexion deficits after surgery. The severity of soft tissue injury and swelling accompanying each distal radius fracture were not characterized. We included different plate designs and sizes, and radiographs of the forearm to measure the length of each plate in relationship to the length of the radius were not obtained. Clinical outcome measurements were limited to group 1 patients, and the follow-up intervals in these cases were short with no preoperative Quick DASH scores for comparison. Electrodiagnostic and ultrasound studies were completed in only 2 patients from the study population. Finally, static rather than dynamic forces were used in assessing FPL tendon excursion in the cadaveric model. Accordingly, the findings may not properly reflect the *in vivo* situation.

Our study provides an expected time course for recovery of thumb IP joint flexion and an anatomic explanation for FPL dysfunction after volar plating of distal radius fractures. We suspect that a spectrum of altered functional lengths of the FPL muscle–tendon unit occurs postoperatively. Careful attention to soft tissue retraction may help to decrease this occurrence. Ancillary tests to assess FPL function are unlikely necessary in the early postoperative period, unless an impediment to FPL tendon excursion, structural damage to the FPL tendon, and/or nerve injury is suspected.

REFERENCES

1. Protopsaltis TS, Ruch DS. Volar approach to distal radius fractures. *J Hand Surg Am.* 2008;33(6):958–965.
2. Keogh P, Khan H, Cooke E, McCoy G. Loss of flexor pollicis longus function after plating of the radius: report of 6 cases. *J Hand Surg Br.* 1997;22(3):375–376.
3. Bell JSP, Wollstein R, Citron ND. Rupture of flexor pollicis longus tendon: a complication of volar plating of the distal radius. *J Bone Joint Surg Br.* 1998;80(2):225–226.
4. Drobetz H, Kutscha-Lissberg E. Osteosynthesis of distal radial fractures with a volar locking screw plate system. *Int Orthop.* 2003; 27(1):1–6.
5. Klug RA, Press CM, Gonzalez MH. Rupture of the flexor pollicis longus tendon after volar fixed-angle plating of a distal radius fracture: a case report. *J Hand Surg Am.* 2007;32(7):984–988.
6. Rozental TD, Blazar PE. Functional outcome and complications after volar plating for dorsally displaced, unstable fractures of the distal radius. *J Hand Surg Am.* 2006;31(3):359–365.
7. Cross AW, Schmidt CC. Flexor tendon injuries following locked volar plating of distal radius fractures. *J Hand Surg Am.* 2008;33(2): 164–167.
8. Arora R, Lutz M, Hennerbichler A, Krappinger D, Espen D, Gabl M. Complications following internal fixation of unstable distal radius fracture with a palmer locking-plate. *J Orthop Trauma.* 2007;21(5): 316–322.
9. Rampoldi M, Marsico S. Complications of volar plating of distal radius fractures. *Acta Orthop Belg.* 2007;73(6):714–719.
10. Orbay JL, Touhami A. Current concepts in volar fixed-angle fixation of unstable distal radius fractures. *Clin Orthop Relat Res.* 2006; (445):58–67.
11. Orbay J. Volar plate fixation of distal radius fractures. Review. *Hand Clin.* 2005;21(3):347–354.
12. Hill NA, Howard FM, Huffer BR. The incomplete anterior interosseous nerve syndrome. *J Hand Surg Am.* 1985;10(1):4–16.
13. Spinner M. The anterior interosseous-nerve syndrome: with special attention to its variations. *J Bone Joint Surg Am.* 1970;52(1):84–94.
14. Mangini U. Flexor pollicis longus muscle: its morphology and clinical significance. *J Bone Joint Surg Am.* 1960;42(3):467–459.
15. al-Qattan MM. Gantzer's muscle: an anatomical study of the accessory head of the flexor pollicis longus muscle. *J Hand Surg Br.* 1996;21(2):269–270.
16. Linburg RM, Comstock BE. Anomalous tendon slips from the flexor pollicis longus to the flexor digitorum profundus. *J Hand Surg Am.* 1979;4(1):79–83.
17. Mangini U. Flexor pollicis longus muscle: its morphology and clinical significance. *J Bone Joint Surg Am.* 1960;42(3):467–470.