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HANDSURGERY

Three-dimensional kinematics of the flexor pollicis longus tendon in relation to the position of the FPL plate and distal radius width

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Abstract

Introduction The standard therapy of intra-articular and extra-articular distal radius fractures consists of open reduction and stabilization using palmar osteosynthesis with an angularly stable plate. The integrity of the flexor pollicis longus tendon (FPLT) may be mechanically affected by the plate, with rupture rates between 1 and 12% reported in the literature, occurring during a postoperative time period from 4 to 120 months. The aim of this study was to investigate the position of the tendon in relation to the distal edge of the plate using high-resolution ultrasonic imaging.

Materials and methods Nineteen patients undergoing osteosynthesis for distal radius fracture in 2015 with the Medartis® APTUS® FPL plate were included in this study. Of these, seven dropped out for various reasons. Therefore, twelve patients with a median age of 52 years (range 24–82 years) were included in the final analysis. High-frequency ultrasound was performed within a median of 28 (range 10–52) weeks by an experienced radiology specialist to locate the FPLT position in two separate wrist positions: (1) wrist held in 0° position and fingers extended and (2) wrist held in 45° of dorsal extension and actively flexed fingers II to V (functional position). For analysis, we used the axial ultrasound videos. Postoperative X-rays and CT scans were included for the analysis, especially the soft-tissue CT scan window for the exact localization of the FPLT. Dynamic ultrasound scanning was used to localize the FPLT in relation to the plate in 0° and functional position of the hand. Using CT scanning, the position of the plate relative to the bone was determined. In this way, we were able to correlate the functional FPLT position with the osseous structures of the distal radius.

Results In all cases, the FPLT was positioned closer to the volar distal edge of the FPL plate in functional position than in 0° position. In four cases, the FPLT did not touch the plate at all and was shown to shift diagonally from radio-volar in ulno-dorsal direction during wrist movement from 0° to functional position, similarly to the sliding of the tendon in the assumed physiological motion sequence. In these cases, in the functional position the center of the FPLT was positioned slightly ulnarly of the center of the distal radius (i.e., less than 50% of the distal radius width measured from the radial border of DRUJ), and positioned more ulnarly than in all other cases (i.e., in which the FPLT came into contact with the plate). In the remaining two-thirds of the cases (eight patients), the FPLT touched the plate during wrist movement from 0° to functional position, shifted in dorsal direction and slid into the plate indentation, irrespective of whether the tendon entered the indentation from the radial or the ulnar side, and independent of the ulnoradial position of the plate. No signs of tendinopathy of the FPLT were found in any of the cases.

Conclusion The results show that the indentation of the Medartis® APTUS® FPL plate reduces the tendon-plate contact and ideally even prevents it entirely. In particular, ulnar positioning of the plate lowers the risk of tendon-plate contact. If the FPLT touches the plate, the tendon pulls into the plate indentation, thus lowering the contact. Consequently, the Soong criteria are not applicable when a FPL plate is used.

Keywords Distal radius fracture · Volar locking plate · Flexor pollicis longus tendon · Rupture · Complication · Outcome

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Introduction

The standard therapy of intra-articular and extra-articular distal radius fractures consists of open reduction and stabilization using palmar osteosynthesis with an angularly stable plate [1–10]. Known complications range from irritation of the extensor and flexor tendons up to ruptures of tendons [11–17]. The flexor pollicis longus tendon (FPLT) is most frequently affected by such complications, with rupture rates between 1 and 12% reported in the literature [11, 18–21], occurring during a postoperative time period of 4–120 months [19, 20]. The main cause of this is the position of the distal edge of the plate [11, 22, 23].

Physiologically, the FPLT runs across the distal palmar radius lip in close proximity to the bone [24]. An anatomically incorrect or excessively voluminous plate design may lead to mechanical irritation and synovialitis of the FPLT and may eventually even cause tendon rupture. The risk of rupturing the flexor tendons in general and the FPLT in particular is especially high if the plate is positioned too distally without respecting the "watershed line" [2, 11, 18, 25, 26] (Fig. 1). In recent years, the clinically established radius plates have been further optimized by reducing the distal plate thickness and placing an indentation in the distal mid third of the plate (APTUS® FPL Plate). This design allows the FPLT to reside in the indentation, especially with distal plate positioning. In this way, the contact between the FPLT and plate is meant to be reduced, thus minimizing tendon irritations (Fig. 2) [2, 3, 26].

The FPL muscle originates at the palmar surface of the radius (proximal and mid third) and adjacent part of the interosseous membrane. The distal end of the FPLT inserts at the palmar aspect of the distal phalanx of the thumb. The trapezium bone serves as a point of deflection for the FPLT. The FPLT is further stabilized and guided by a fibrous band

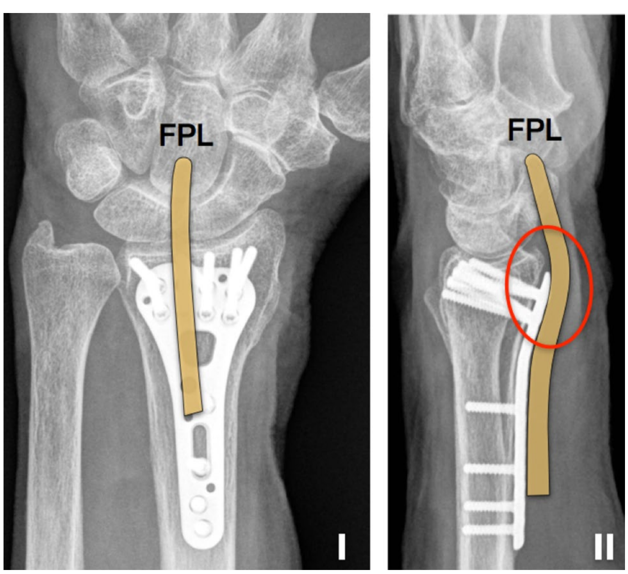

Fig. 1 X-ray (**I** posteroanterior plain; **II** lateral plain) of volar plate (without indentation) osteosynthesis of distal radius. *FPL* exemplary position of the flexor pollicis longus (FPL) tendon

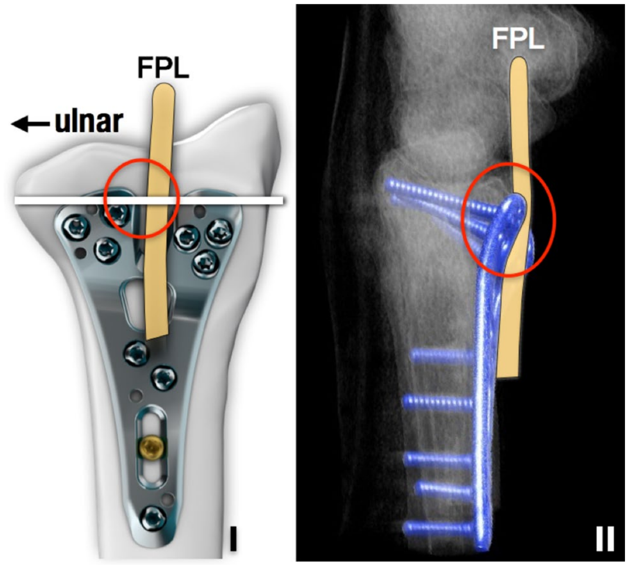

Fig. 2 **I** Frontal view APTUS® flexor pollicis longus (FPL) Plate on an osseus scheme; white bar: axial plane representing examination level. **II** Lateral view APTUS® FPL Plate in 3D CT reconstruction; red circle: area used for measuring distance between flexor pollicis longus (FPL) tendon (FPLT) and plate (compare Fig. 5); *FPL* exemplary position of the FPLT

(an additional "pulley") at the level of the trapezio-metacarpal joint [27].

The position of the tendon at the level of the palmar lip of the distal radius depends on the position of both the thumb and the wrist joint. When the wrist is fixed in neutral or radial deviation position, the FPLT resides in a more ulnar position during abduction of the thumb, compared to neutral position and adduction/flexion of the thumb. In contrast, in the ulnar deviation position of the wrist, the FPLT is positioned more ulnarly in the adduction/flexion position of the thumb than in neutral or abduction position of the thumb. However, during abduction of the thumb, the FPLT is most extended in ulnar deviation of the wrist when compared to neutral position or radial deviation [28]. In addition, the FPLT is displaced in ulnar direction in the area of the volar lip of the radius during extension of the wrist joint, while there is an additional deflection of the FPLT in ulnar direction during extension of the wrist joint via the distal pole of the scaphoid [29].

Ulnar displacement of the FPLT is further increased during flexion of fingers II–V [30]. When extending the wrist joint, the FPLT runs more dorsally and thus closer to the distal volar lip of the radius, a phenomenon that is even more pronounced during flexion of fingers and active muscle contraction [25, 30]. In contrast, in neutral position of the wrist joint, the trapezium bone resides in a more palmar position in the coronal plane than the distal radius lip, causing palmar displacement of the FPLT [29].

The main function of the FPLT is flexion of the interphalangeal (IP) and metacarpophalangeal (MCP) joints and adduction of the thumb [31]. Therefore, the FPL muscle has an important function for grasping small objects (i.e., extension of the wrist joint, combined with abduction of the thumb (trapezio-metacarpal joint), and flexion of IP and MCP joints of the thumb) and for a powerful grip (i.e., extension and ulnar deviation of the wrist joint, adduction and opposition of the thumb, and flexion of IP and MCP joints) [32]. Consequently, location of the FPLT in the coronal plane depends markedly on the position of the fingers and wrist joint.

However, the location of the FPLT at the distal radius may vary, depending on the orientation of the wrist joint and fingers [27, 30]. Since the position of a distal radius plate in the coronal plane (radio-ulnar direction) varies, it is difficult to predict whether the FPLT will lie in the plate indentation as intended, and in which wrist orientation. Thus, main aim of this study was to investigate the actual position of the tendon in relation to the plate by high-resolution ultrasonic imaging, using variable wrist orientations.

Materials and methods

After approval of the study protocol by the local ethical committee, all 19 patients treated between January 2015 and December 2015 with the Medartis® APTUS® FPL Plate (Medartis AG, Basel, Switzerland) were invited to attend the follow-up investigation.

Of the original 19 patients, 7 patients were excluded. Two of the excluded patients continued their treatment in their hometown, 1 patient had a preexisting FPL weakness, 1 patient refused study participation, 2 patients underwent premature removal of the plate because of their own request, and 1 patient was excluded because of bony overgrowth in the area of the distal edge of the plate. Consequently, 12 patients (7 women and 5 men) were included with a median age of 52 years (range 24–82 years) and follow-up interval with a median of 27.5 (range 10–52) weeks.

Surgical procedure

In all cases, the standard palmar-radial approach between the flexor carpi radialis tedon and radial artery was chosen. After separation of the fascia and blunt dissection of the FPLT in ulnar direction, the pronator quadratus muscle was transected in close proximity to its radial insertion and shifted in ulnarly. After reduction, the fracture was stabilized with the plate using an angle-stabilized technique. Then, the pronator quadratus muscle was sewed back if possible, the subcutaneous layer was sutured, and the skin was closed.

Postoperative patients were immobilized for 5 weeks with a removable plastic forearm splint and subsequently underwent hand therapy after splint removal.

Ultrasound examination

Ultrasonic imaging is a well-established diagnostic procedure for wrist examinations, especially for the diagnosis of soft-tissue pathologies such as tendon lesions [33–36].

For ultrasound studies, we used a LOGIQ S8® ultrasound scanner equipped with a high-resolution 6–15 MHz ML (Matrix Linear) probe (General Electrics Austria®, Vienna, Austria). Recordings of movements in the axial plane were analyzed in the 0° position and extended position of the wrist joint for both the operated and nonoperated sides.

Ultrasonic scans were obtained with supination of the forearm and 45° flexion of the elbow joint. The shoulder was held in 0° of abduction. The distal forearm was placed on a prefabricated splint. The ultrasound transducer was positioned perpendicularly to the skin surface without applying any force, in parallel to the transverse skin fold overlying the wrist joint (rascetta/linea carpi palmaris distalis). Video sequences of 10 s duration were recorded, with the thumb passively extended and flexed (Fig. 3).

To consider the variable positions of the FPLT during changes of hand position, investigations were carried out with the wrist held in 0° position and fingers extended (Fig. 4I), and with the wrist held in 45° of dorsal extension and actively flexed fingers II–V (functional position) [10, 11, 13] (Fig. 4II).

Radiological examination

At follow-up, radiographic images were examined by an independent radiologist. Fractures of the distal radius were classified according to AO/ASIF classification [37] into C1 ($n=1$), C2 ($n=3$), and C3 ($n=8$) fractures.

For each patient, the routinely obtained X-rays and CT scans (CT scanner: Siemens Somatom Definition AS®, Siemens AG Austria, Vienna, Austria) were evaluated. During CT scans, the patients were placed in prone position, with the arm placed overhead in pronation and the wrist joint and hand partially placed on a pillow. Both bone and soft-tissue images in CT scans were evaluated. Orientation of the FPLT in soft-tissue images was assessed simultaneously in all three planes (i.e., sagittal, axial, and coronal planes). Exact dimensions of the FPL plate were provided by Medartis AG, Switzerland. In this way, we were able to accurately locate every plane in ultrasound and CT scans. In the analysis of CT scans, an individual factor to correct metal artifacts for each measurement and patient was calculated. This corrective factor was used for further analyses. To locate the FPLT, we analyzed ultrasound and CT scans in the

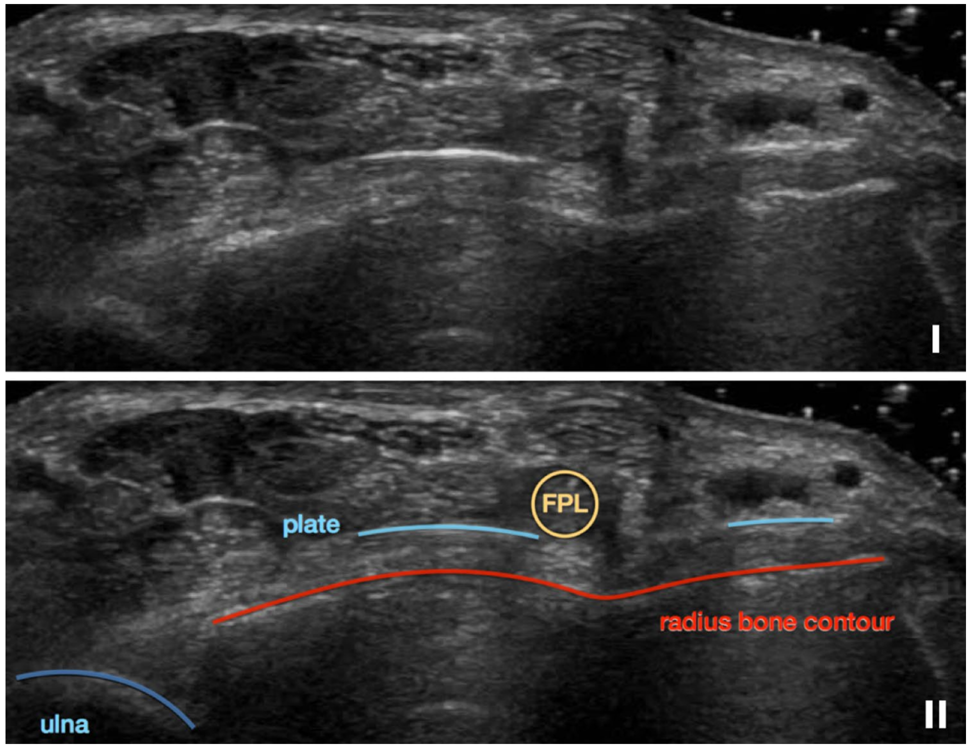

Fig. 3 Ultrasonic image of axial plane at examination level (see Fig. 2I); *FPL* flexor pollicis longus (FPL) tendon, *ulna* ulnar head, *plate* both distal legs of FPL plate defining plate indentation in between

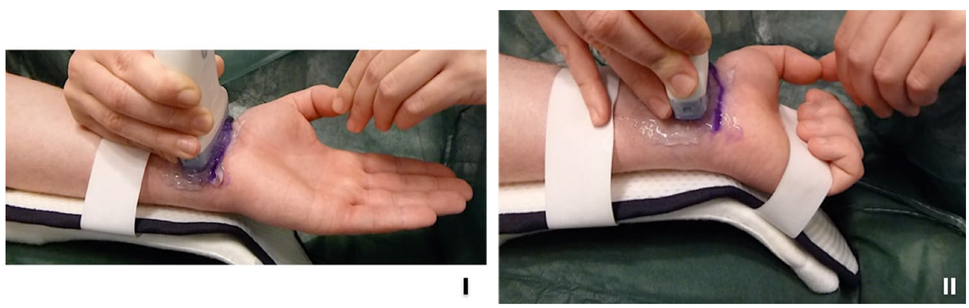

Fig. 4 **I** 0° position: wrist held in 0° position, fingers extended; **II** functional position: wrist held in 45° of dorsal extension, fingers II–V actively flexed. Position of ultrasound transducer: perpendicular to skin surface, parallel to transverse skin fold overlying wrist joint (rascetta/linea carpi palmaris distalis), no force applied

same plane of the FPL plate for all patients, i.e., in the axial plane of the FPL plate at the level of the most radial point of the ulnar border of the distal indentation of the FPL plate (Fig. 2, Image I). In lateral X-rays, the angle of dorsopalmar inclination of the distal joint surface of the radius was measured between the connecting line of the dorsal and palmar joint edges and the longitudinal axis of the radius shaft.

In conclusion, we determined the dynamic movements of the FPLT in relation to the plate indentation by ultrasonic scanning, while the position of the plate relative to the distal radius and static position of the FPLT was assessed by CT scanning. Joint angles were measured using X-ray images.

The position of the FPLT was determined in relation to the plate in both the 0° and functional position of the hand at two points, i.e., the distal ulno-volar and distal ulno-dorsal aspects of the indentation of the plate. These two points of possible contact between the plate and FPLT have to be viewed separately, because their importance depends on the variable positions of the FPLT and plate, as follows:

- During movement of the tendon in the sagittal plane from a palmar location into dorsal direction, the tendon will first touch the palmar edge of the plate indentation (Fig. 5, Image I point A).
- If the tendon moves in the coronal plane in radio-ulnar direction, it will first touch the dorsal edge of the plate indentation (Fig. 5, Image II point B).

In addition, the position of the plate in relation to the bone was considered:

- Plates positioned 1.5 mm and more proximally of the ulnar watershed line in the CT were classified as “proximal”. Thus, all other plates were in distal position.

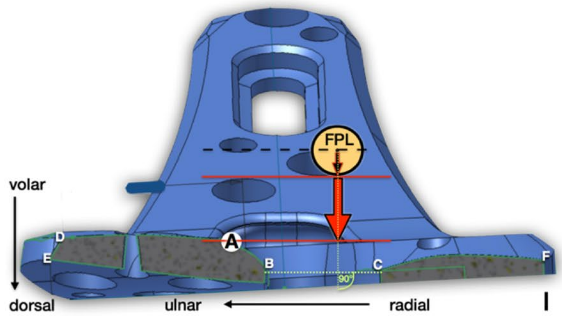

Fig. 5 Cross section of the flexor pollicis longus (FPL) plate at level of examination (compare Fig. 2); **I** point A: distal ulno-volar edge of plate indentation; red arrow: volar-dorsal direction of measurement (sagittal plane); **II** point B: distal ulno-dorsal edge of plate indentation; red arrow: radio-ulnar direction of measurement (coronal plane). Black arrow: distance between center and edge of flexor pollicis longus (FPL) tendon (FPLT). For identification of correct examination level [axial section of the flexor pollicis longus (FPL) plate], distances between corner points A to F were measured and compared to technical data provided by Medartis®. Distance measurement between border/center of flexor pollicis longus (FPL) tendon (FPLT) to line through A or B, respectively, was conducted either parallelly (**I**) or perpendicularly (**II**) to reference line through B and C

- Plates whose center lay ulnarly from the center of the distal radius width in the CT were classified as “ulnar”. Thus, all other plates were in radial position.

Furthermore, detailed analysis revealed that the movements of the FPLT were markedly influenced by the position of the plate. However, statistical analysis was hampered by the small number of patients treated. Thus, we attempted to group situations that were anatomically similar to confirm our hypotheses.

Statistical analysis

Statistical analysis was performed using binominal mass function and Wilcoxon test. Data are expressed as medians and ranges. Threshold for statistical significance was $p < 0.05$.

Results

Position of the FPLT relative to the distal ulno-volar edge of the plate indentation (point A, Fig. 5I)

This analysis was conducted in volar-dorsal direction, thus, in the sagittal plane, to establish whether and when the FPLT and plate came into contact and under what circumstances the FPLT moved into the indentation of the plate. Ultrasound and CT examinations confirmed that the center of the FPLT was positioned more dorsally in the functional position than in 0° position of the hand in all the patients (Fig. 6I).

In 6 patients, the distal end of the plate showed a proximal position (i.e., distal edge of the plate positioned ≥ 1.5 mm proximally from the ulnar watershed line).

- In four of these six patients, the dorsal edge of the FPLT lay volarly to the edge of the plate in both positions of the hand, thus precluding a contact between the FPLT and plate. In one case, the plate was positioned exactly 1.5 mm proximally of the ulnar watershed line, but the FPLT did not touch the plate. In this patient, the dorsal-palmar inclination of the distal joint surface of the radius amounted to nearly 10°, and the plate fitted tightly to the bone.
- In two of these six patients, where the plate was positioned 2 mm proximally of the ulnar watershed line, there was a gap of more than 1 mm between the bone and the distal ulnar edge of the plate. In these patients, dorso-volar inclination of the distal joint surface of the radius was < 6.5°. In this situation, the dorsal edge of the FPLT was located in the indentation and, thus, lay dorsally of point A, in both positions of the hand.

In another six patients, the plate was positioned distally (i.e., < 1.5 mm away from the ulnar watershed line). In all these six cases, the dorsal edge of the FPLT was located dorsally of point A in the functional hand position. Consequently, these cases differed only in the 0° position with respect to the position of the FPLT relative to the volar edge of the plate (point A).

- In two patients, in the 0° position of the hand, the FPLT resided volarly in relation to the distal edge of the plate and, thus, did not touch the plate, although CT images revealed a gap of at least 1 mm between the distal ulnar edge of the plate and the bone. In these patients, dorso-volar inclination of the distal joint surface of the radius was at least 10°.

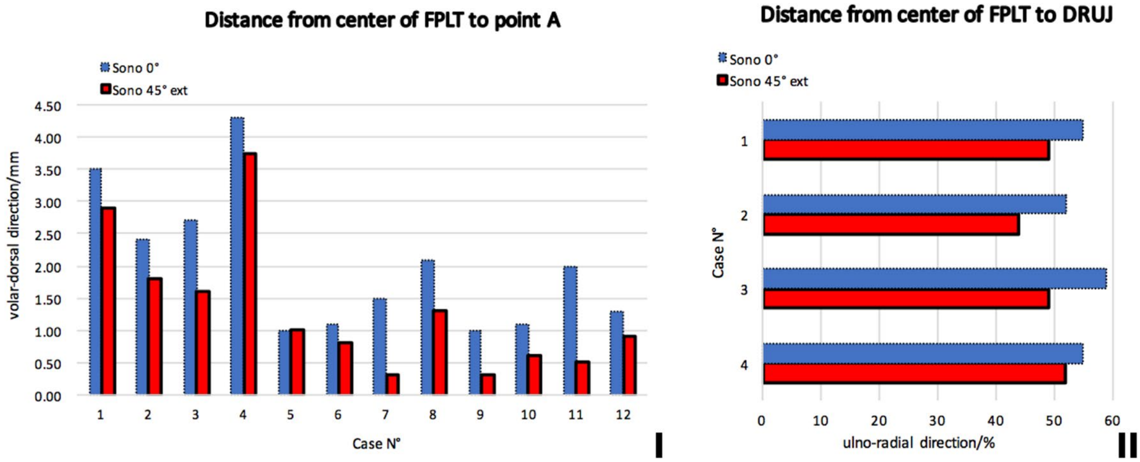

Fig. 6 **I** Distance between center of the flexor pollicis longus (FPL) tendon (FPLT) to point A (in mm); **II** distance between center of FPLT to radial border of distal radio-ulnar joint (DRUJ) in % of distal radius width; Case no. 4: maximum extension of wrist joint of 30°; blue bars: 0° position; red bars: functional position

- In one patient, the dorsal edge of the FPLT was located in the same plane as the volar edge of the plate indentation (point A) in the 0° position of the hand.
- In the remaining three patients, the FPLT was located dorsally of the volar edge of the plate indentation (point A) in both orientations of the hand.

Thus, in 7 out of the 12 patients, the dorsal edge of the FPLT was located volarly or in the same plane as the volar edge of the plate indentation in the 0° position. In these cases, the center of the FPLT is located at a distance of 59–50% of the distal radius width away from the radial border of the distal radioulnar joint (DRUJ).

Position of the FPLT relative to the distal ulno-dorsal edge of the plate indentation (point B, Fig. 5II)

This investigation was conducted mainly in radio-ulnar direction to examine whether and how the FPLT shifted in the coronal plane. In all cases, CT images showed the center of the FPLT to be more radially positioned, median of 64% (range of 67–58%) of the distal radius width away from the radial border of the DRUJ (Fig. 7I), than shown in either hand orientation at ultrasonic examination.

Ultrasonic examination

- In 5 of the 12 patients, the center of the FPLT was located radially of the ulno-dorsal edge of the plate indentation (point B) in the 0° position of the hand, whereas it was located more ulnarly to point B in the functional position. In one of these five patients, the center of the FPLT was located radially to point B in both positions of the hand. This patient exhibited a restricted range of motion, though, with maximum extension of the wrist joint of 30° even at 10 weeks after the operation.
- In the remaining seven patients, the center of the FPLT was positioned ulnarly of the ulnar edge of the plate

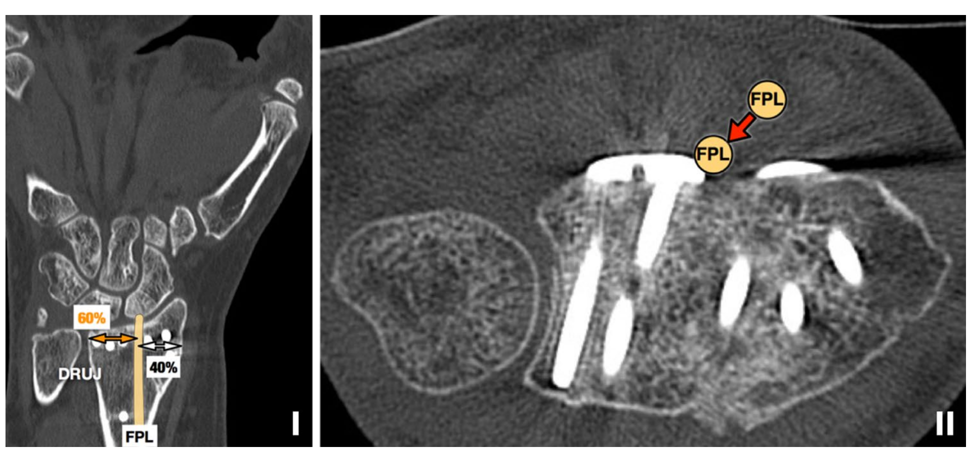

Fig. 7 **I** CT image coronal plane: position of the flexor pollicis longus (FPL) tendon (FPLT) at distal volar edge of radius in 0° position (to slight wrist flexion), center of FPLT is positioned at about 60% of distal radius width measured from radial border of distal radio-ulnar joint (DRUJ); **II** CT image axial plane (examination level compare Fig. 2): diagonal shift (red arrow) of FPLT from radio-volar to ulno-dorsal position during wrist movement from 0° to functional position

indentation in both the 0° and functional position of the hand.

Dynamic shift of the FPLT during wrist joint movement from 0° to functional hand position

A three-dimensional analysis (i.e., volar-dorsal and radio-ulnar directions combined) was performed to assess the dynamic shift of the FPLT during wrist joint movement from the 0° position to functional position of the hand in relation to the plate and distal radius width. Thus, we aimed to assess whether and when the FPLT touches the plate (Fig. 8).

During wrist joint movement from the 0° position to functional hand position, the FPLT shifted in volar-dorsal direction, as pointed out above, in all patients. Positioning of the FPLT relative to the plate was as follows:

- In four patients, the position of the FPLT relative to the plate was volar in both hand orientations, and the FPLT did not touch the plate. In these cases, the dynamic shift of the FPLT during wrist movement from 0° to functional position occurred diagonally from radio-volar to ulno-dorsal position (Fig. 7II) and was not affected by the plate. An additional analysis in relation to the distal radius width revealed a maximum range of movement of the FPLT in the coronal plane of 10% of the width of the distal radius during wrist joint movement from the 0° position to functional hand position. In this one case of maximum range of motion, the plate was positioned 1.5 mm proximally of the ulnar watershed line.

  During functional hand orientation, the center of the FPLT was positioned slightly ulnarly of the center of the radius in these patients (i.e., 44–49% of the distal radius width measured from the radial border of DRUJ) (Fig. 6II).
- In the remaining eight patients, the FPLT resided dorsally of point A at least in the functional position of the hand and touched the plate. In these cases, the tendon occupied the indentation of the plate, particularly in the functional hand position.

  - In four patients, the FPLT moved in ulnar direction during wrist joint movement from the 0° to the functional position, but the movement was limited by the ulnar edge of the indentation.
  - In the other four patients during wrist joint movement from the 0° to the functional position, the tendon slid into the indentation in radial rather than in ulnar direction contrary to the assumed physiological movement. In these four patients, the plate exhibited a radial position on the distal radius.
  - Based on the findings in these 8 out of 12 patients, the sliding of the FPLT into the plate indentation (assuming a probability of $< 69\%$) constitutes a significant study finding ($p < 0.05$; binominal distribution).

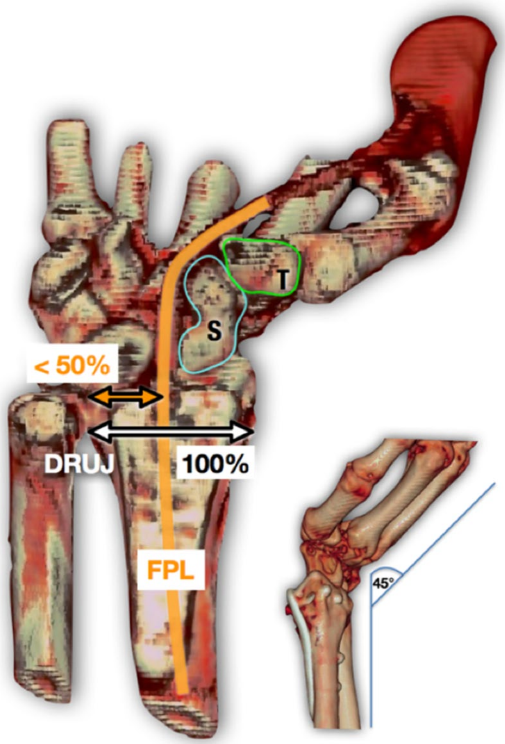

Fig. 8 3D CT reconstruction in 45° wrist extension, location of the flexor pollicis longus (FPL) tendon (FPLT) at distal volar edge of radius, and center of FPLT is positioned at less than 50% of distal radius width measured from radial border of distal radio-ulnar joint (DRUJ); S = Os scaphoideum, T = Os trapezium

Exclusion of tendon irritations

None of the patients showed any signs of tendon irritation as manifested by hypervascularization of the tendon sheath, structural alterations, or thickening of the tendon. There was no significant difference in tendon thickness between the operated and nonoperated wrists ($p > 0.05$).

Discussion

Distal positioning of volar plates to stabilize intra-articular radius fractures is considered a risk factor for tendon irritation and rupture of the flexor tendons, particularly the FPLT. In the literature, the Soong criteria are discussed as predictors of potential flexor tendon irritation. These criteria are based on analysis of lateral plain x-ray images of the distal radius and do not take into account the functional movements of the FPLT in relation to the distal edge of the plate [38–44].

The areas of potential stress on the FPLT identified by ultrasound imaging are of particular interest in this context. Nanno et al. demonstrated that the FPLT runs in closest vicinity to the radius or volar plate if the wrist joint is extended and the fingers are flexed [30]. Because this wrist position is used very frequently in daily life, it is generally called the functional position. Many studies demonstrated that the "dart thrower's arc motion" is applied permanently in daily life; in this motion arc, dorsal extension and radial deviation of the wrist joint and flexed fingers represent an end position of the movement axis required for the fine grip (finger I–III) [32, 45, 46]. In contrast, to obtain optimized muscular pretensioning, the powerful grip is performed in extension and ulnar deviation of the wrist joint and flexed position of fingers. In this study, the main focus was on the functional position (wrist held in 45° of dorsal extension and actively flexed fingers II–V).

The findings of this study confirm the results of Nanno et al. [30] that the FPLT resides in a position closest to the radius during extension of the wrist joint and flexion of the fingers (i.e., functional position) when compared to the 0° position of the hand. Closer examination of the study findings revealed that the FPLT occupied the indentation of the APTUS® FPL Plate especially in situations where there was a gap between the plate and the distal volar edge of the radius. Yet, the indentation of the plate was less important, the closer the dorso-volar inclination of the radiocarpal joint surface of the distal radius was restored towards the normal inclination of 10° [47].

We hypothesize that adequate dorso-volar inclination protects the FPLT by compensating for a slightly protruding distal edge of the plate, thus minimizing the contact between the tendon and the distal radial lip or distal edge of the plate, respectively. Reduction of contact of the FPLT at adequate dorso-volar inclination (angle: ~10°) of the joint surface of the distal radius may be explained by the carpal bones located in a more volar position [29]. However, if there is a gap of more than 1 mm between the plate and volar cortical bone of the distal radius, the FPLT moves much closer to the distal edge of the plate. As Matityahu et al. [25] showed in a biomechanical investigation, flexion of the IP and MCP joints of the thumb carried out against resistance displaces the FPLT further towards the distal radial lip. This leads us to hypothesize that in a powerful grip the FPLT moves even more dorsally towards the distal radial lip than in the functional position assessed in this study.

The functional movement of the FPLT in ulno-dorsal direction depends on several factors. In this respect, the motion axis of the wrist joint in the coronal plane (ulnar and radial deviation) and sagittal plane (flexion and extension of the wrist) as well as the position of the fingers II–V and especially the position of the thumb is of particular importance [28, 29, 31]. In this investigation, we mainly focused on extension of the wrist without radial or ulnar deviation (functional position), active flexion of the fingers II–V, with the thumb positioned in slight abduction. Ultrasonic scanning revealed that, in 0° position, the center of the unrestricted FPLT (i.e., in the absence of contact with the plate) resides nearly centrally to slightly radially of the center of the distal radius width (i.e., at a distance of 59–48% of the distal radius width measured from the radial border of DRUJ). If the FPLT is shifted by 10% of distal radius width (the maximum measured range of movement of the FPLT in the coronal plane) in ulnar direction during wrist movement from the 0° to functional position, the center of the tendon will be situated in a position 38–49% of the width of the distal radius measured from the radial border of DRUJ. Taking study findings reported by other authors into account, we assume that the FPLT slides into an even more ulnar position and will reside closer to the bone during powerful grip of the hand [28, 32, 48].

The results of this study indicate that, when in contact with the plate, the FPLT chooses the route of least contact and thus makes use of the indentation of the plate. This even occurs if the plate is fixed more radially and the tendon is deviated in radial direction by the plate. Thus, the indentation of the plate effectively reduces the contact between the plate and FPLT even if the plate is mounted in a less physiological position, i.e., in radial position lateral of the midline of the radius. This study confirmed contact minimizing between the FPLT and the distal edge of the plate, because none of our patients showed any signs of irritation of the FPLT, such as hypervascularization, nor was there any evidence of structural alterations such as swelling of the FPLT in the operated wrist when compared to the nonoperated wrist at follow-up examination [49].

Consequently, the Soong criteria are not applicable when using the FPL plate, because the indentation of the plate is not visualized in lateral x-ray images. Therefore, in x-ray images, no conclusions with respect to the actual contact between the tendon and plate can be drawn.

There are several limitations to this study, which have to be considered before interpretation. The study group of 12 patients was small. In addition, comparison of the two test procedures (ultrasound imaging and CT scanning) should be interpreted with caution, because patient´s positioning varied and the two techniques are associated with differing artifacts.

To reduce the influence of artifacts, we focused only on the position of the center of the FPLT in direct comparisons of both procedures. With respect to variable patient positioning, it is not clear to what extent supination and pronation positions affected the tension and location of the FPLT at the level of the distal lip of the radius. However, we assume that the position of forearm pronation, slight wrist flexion, and ulnar deviation (i.e., reflecting patient positioning during CT scanning) results in a relatively straight course of the FPLT (without deflection of the FPLT by trapezium bone and scaphoid) and, thus, in a rather radial and volar position of the tendon. This study's findings confirm these assumptions. However, during a forced grip, the FPLT might be more dorsally than tested in this study.

When comparing CT and ultrasound scans obtained in the volar-dorsal direction, it should be kept in mind that we placed the hand and wrist of some patients on a pillow for CT scanning. This might have increased the volar pressure on the tendon resulting in dorsal displacement of the FPLT.

The position of the flexor tendons of digits II–IV in relation to the plate were not considered, but these should probably be taken into consideration in the area of the ulnar section of the plate. Furthermore, it must be assumed that postoperative soft-tissue scarring in the operated area may affect the movement of flexor tendons, which was not considered in this study. We were unable to establish whether reconstruction of the pronator quadratus muscle had a protective effect on tendon irritation, because muscle reconstruction was carried out in all patients but one for whom no contact between the FPLT and plate was noted. Tendon ruptures after volar distal radius plating typically occur between 4 and 120 months after surgery [18, 19]. As the follow-up interval was a median of 28 weeks, possibly later occurring ruptures are not covered in this study. Therefore, further long-term investigations with a higher number of patients are needed to confirm the protective role of the indentation of the FPL plate for the FPLT.

Conclusion

Dynamic ultrasound scanning was used to localize the FPLT in relation to the plate in 0° and functional position of the hand. Using CT scanning, the position of the plate relative to the bone was determined. In this way, we were able to correlate the functional FPLT position with the osseous structures of the distal radius. In those cases where there was no contact between the tendon and plate, the FPLT was shown to shift diagonally from radio-volar in ulno-dorsal direction during wrist movement from the 0° to the functional position, similarly to the sliding of the tendon in the assumed physiological motion sequence. In these cases, in the functional position the center of the FPLT was positioned slightly ulnarly of the center of the distal radius (i.e., less than 50% of the distal radius width measured from the radial border of DRUJ), and positioned more ulnarly than in all other cases (i.e., in which the FPLT came into contact with the plate).

In the cases where the FPLT touched the plate during wrist movement from the 0° to the functional position, the tendon shifted in dorsal direction and slid into the plate indentation, irrespective of whether the tendon entered the indentation from the radial or ulnar side, and independent of the ulnoradial position of the plate.

The results show that the indentation of the Medartis® (APTUS®) FPL plate reduces the tendon-plate contact and ideally even prevents it completely. In particular, ulnar positioning of the plate lowers the risk of tendon-plate contact (Fig. 8). If the FPLT touches the plate, the tendon pulls into the plate indentation, thus lowering the contact. Consequently, the Soong criteria are not applicable when a FPL plate is used.

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Compliance with ethical standards

Conflict of interest Linda Schlickum, M.D. attended the International Bone Research Association (IBRA) scholarship program C for carrying out this study. All other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Institutional review board approval was obtained for this study.

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