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ORIGINAL ARTICLE

Investigating the minimum distance between the finger flexor tendons and distal radius during wrist and finger positions in healthy people

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Abstract

Purpose Rupture of the flexor pollicis longus (FPL) and index flexor digitorum profundus (FDP2) tendons often occurs after locking plate fixation for distal radius fracture. This study aimed to determine the shortest tendon-radius distances of different hand positions.

Methods Fifty-nine hands of 30 healthy volunteers were studied. Distances between the FPL or FDP2 and distal radius were calculated in six wrist positions: 30° palmar flexion, neutral, 30° dorsiflexion, 60° dorsiflexion, maximum dorsiflexion, and 40° ulnar deviation with three finger positions (full extension and flexion of fingers, full flexion of the thumb or index finger, and full extension of the other four fingers). The shortest distance between the FPL or FDP2 and distal radius was noted.

Results The shortest distance between the FPL and distal radius was during maximum wrist dorsiflexion with isolated thumb flexion. The distance between the FDP2 and distal radius was shortest with all-finger flexion in 30° wrist dorsiflexion.

Conclusions It is necessary to measure the distance between the FPL and distal radius in maximal wrist dorsiflexion with full flexion of the isolated thumb, as the shortest distance was observed with flexion of the isolated thumb. On the contrary, we recommend measuring the distance between the FDP2 and distal radius in 30° wrist dorsiflexion with flexion of all fingers.

Keywords Distal radius · Flexor pollicis longus · Index flexor digitorum profundus · Ultrasound

Introduction

Internal fixation using a volar locking plate to treat distal radius fractures was first reported in 2002. Because of its excellent initial fixation and convenience, it rapidly became the standard treatment for distal radius fracture [1]; however, it has been reported to cause the ruptures of the flexor pollicis longus (FPL) and index flexor digitorum profundus (FDP2) [2].

The incidence of FPL rupture after conservative treatment was found to be 0.18% [3], while, in cases with locking plate use, the incidence was 12% [4–6]. As such, clinicians have attempted to determine the cause of this occurrence. The watershed line, described by Orbay and Fernandez [1], is where the flexor tendon group most closely approaches the radius. When the plate is fixed distal to the watershed line, the risk of tendon rupture increases due to irritation between the plate and the flexor tendon group [7].

Soong et al. [8] reported that the risk of tendon rupture increased not only when the position of the volar locking plate was more distal than the volar rim of the distal radius but also when the plate protruded more palmar than the volar rim of the distal radius. The risk of FPL rupture is determined using the classification of the plate's position that is visualized on radiographs (lateral view); however, radiographic evaluation is limited as the FPL cannot be directly visualized [9].

With the advances in ultrasonic instruments, noninvasive evaluation of tendons is now possible. We hypothesized that if the distance between the FPL or FDP2 and the plate can be determined by ultrasonography, the signs of tendon rupture and injury can be also determined, which would enable clinicians to prevent rupture.

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If the shortest distance between the finger flexor tendons and distal radius can be determined with respect to a certain position of the wrist and fingers, this knowledge may be applied to the distance between the finger flexor tendons and the locking plate. Decreasing the distance between the flexor tendon and the plate leads to friction; therefore, determining the minimum distance could likely help to predict tendon rupture.

In this study, we utilized ultrasonic instruments during position changes of the wrist and fingers to determine the position in which the distance between the flexor tendon and distal radius was the shortest.

Materials and methods

This study included 59 hands of 30 healthy volunteers (5 men, 25 women; mean age, 44.2 years; age range, 22–59 years) without a history of tendon damage to the upper extremities or neurological deficit. One hand from a female subject was excluded due to a history of distal radius fracture. The higher number of women recruited into the study was entirely by chance. All subjects were right-hand dominant, and no subject had wrist pain at the time of the study. The physical characteristics were mean grip strength of 27.5 kg (range 17.0–55.2 kg) and mean active angles of 98.1°, 74.7°, 88.3°, and 68.9° on supination, pronation, flexion, and extension, respectively. The mean passive angle of wrist extension was 93.9°.

The ultrasonic instrument used was a SonoSite Edge probe (6–13 MHz) (Fujifilm Corporation, Saitama City, Japan). Subjects sat on a chair and then placed their forearm on a table with the shoulder in the neutral position, the elbow in approximately 45° flexion, and the forearm in supination. The subject's wrist was fixed to a custom-made splint at each angle, and the transducer was attached to the volar side of the subject's wrist. The subjects were asked to flex and extend their fingers, and the positions of the FPL and FDP2 were confirmed. The distance between the FPL or FDP2 and distal radius was measured by holding the transducer on the distal radius of the wrist at a 90° angle to the volar skin of the forearm on longitudinal ultrasonography (Fig. 1).

Measurements included the distances between the FPL or FDP2 and distal radius in each of six wrist positions: 30° palmar flexion, neutral, 30° dorsiflexion, 60° dorsiflexion, maximum dorsiflexion, and 40° ulnar deviation with each of three finger positions (full extension and full flexion of all five fingers, full flexion of the thumb or index finger individually, and full extension of the other four fingers). The term all-finger flexion was defined as a full grip. The muscle covered the watershed line when the subjects moved their fingers, but the shortest distance between the tendon and the watershed line was measured with the tendon itself, not the muscle component (Fig. 2).

Fig. 1 Longitudinal ultrasound examination in this study

All ultrasonic examinations were performed by a single orthopedic surgeon. He is the first author of the manuscript; he has 1 year of experience in performing ultrasonic examinations. The results were calculated as the average of three test results per hand. To measure the error of the examiner who performed the ultrasonic examinations, the distance between the FPL or FDP2 and distal radius in the neutral position of one hand with the thumb and the index flexion positions was measured 32 times in each position; the standard error was found to be 0.02 mm. Paired samples *t* test was used for statistical examination, and the significance level was set to a p value of < 0.05.

Results

Distance between the FPL and distal radius

In all-finger extension, 30° palmar flexion yielded a significantly longer distance than that in the neutral position ($p = 0.003$). In addition, a significantly longer distance was found in the neutral position than in 30° dorsiflexion ($p = 0.00$) and in maximum dorsiflexion than in 40° ulnar deviation ($p = 0.0002$), respectively.

In all-finger flexion, 30° palmar flexion yielded a significantly longer distance than that in the neutral position ($p = 0.00$). Moreover, a significantly longer distance was seen in the neutral position than in the 30° dorsiflexion position ($p = 0.00$).

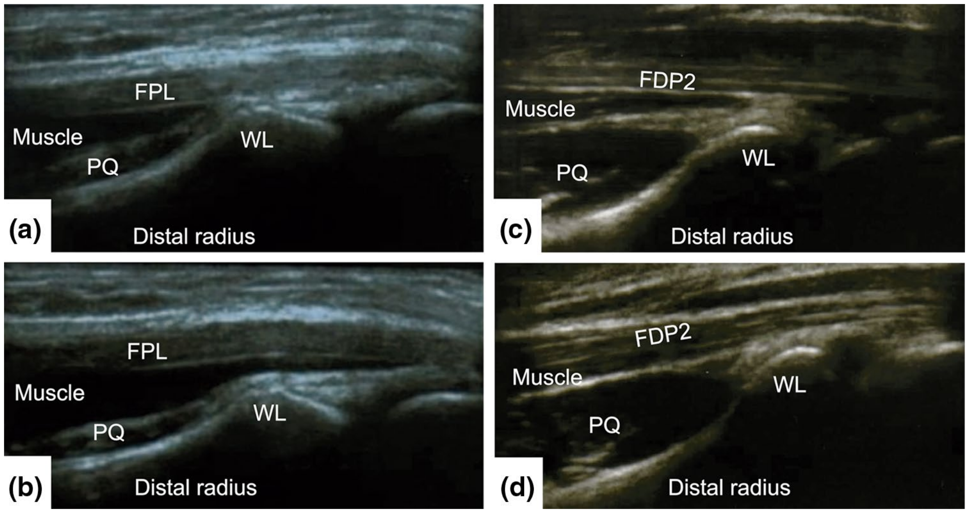

Fig. 2 Ultrasound image in the FPL and FDP2 longitudinal direction at the distal end of the radius. **a** Thumb flexion; **b** all-finger extension. The shortest distance was measured on the screen of the ultrasonic device from the FPL to the WL (distal radius). In many subjects, the muscle of the FPL covered the WL through isolated thumb extension; therefore, the distance between the FPL and WL was longer. **c** All-finger flexion, d: all-finger extension. The shortest distance was measured on the screen of the ultrasonic device from the FDP2 to the WL. In many subjects, the muscle of the FDP2 covered the WL through isolated index extension; therefore, the distance between the FDP2 and WL was longer. *FPL* tendon of the flexor pollicis longus, *FDS2* tendon of the index flexor digitorum profundus, *Muscle* muscle of the FPL, *PQ* pronator quadratus, *WL* watershed line

During flexion of the isolated thumb, 30° palmar flexion yielded a significantly longer distance than that in the neutral position ($p = 0.00$). In addition, a significantly longer distance was observed in the neutral position than in 30° dorsiflexion ($p = 0.00$), in 30° dorsiflexion than in 60° dorsiflexion ($p = 0.008$), and in 60° dorsiflexion than in maximum dorsiflexion ($p = 0.00$), respectively.

When the wrist was in the neutral position, all-finger extension yielded a significantly longer distance than those in all-finger flexion ($p = 0.00$) and isolated thumb flexion ($p = 0.0001$), respectively; no significant difference was observed between all-finger flexion and thumb flexion. In maximum dorsiflexion of the wrist, a significantly longer distance was found in all-finger extension than in all-finger flexion ($p = 0.008$), in all-finger extension than in isolated thumb flexion ($p = 0.00$), and in all-finger flexion than in isolated thumb flexion ($p = 0.003$), respectively.

Overall, the distance between the FPL and distal radius was shorter in all-finger or isolated thumb flexion than in all-finger extension, and was shorter in dorsiflexion of the wrist than in the neutral position. The shortest distance was noted in maximum dorsiflexion of the wrist with isolated thumb flexion (Fig. 3).

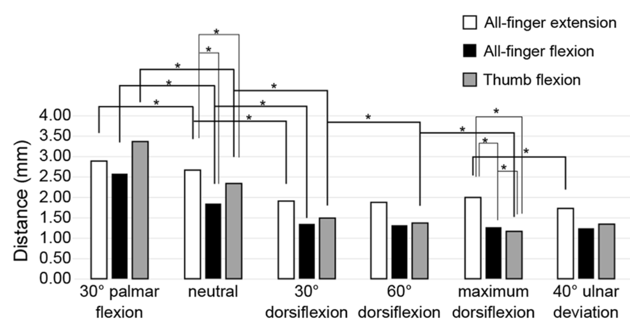

Fig. 3 Distance between the flexor pollicis longus and watershed line at various wrist positions with various finger positions. *$p < 0.05$

Distance between the FDP2 and distal radius

In all-finger flexion, 30° palmar flexion yielded a significantly longer distance than that in the neutral position ($p = 0.00$). For both all-finger flexion and all-finger extension, a significantly longer distance was found in the neutral position than in the 30° dorsiflexion position ($p = 0.04$ and $p = 0.01$, respectively).

In isolated index finger flexion, a significantly longer distance was found in 30° palmar flexion than in the neutral position ($p = 0.00$) and in the neutral position than in 30° dorsiflexion position ($p = 0.013$), respectively. Moreover, a significantly longer distance was found in all-finger extension than in all-finger flexion when the wrist was in the neutral position ($p = 0.00$), but there was no significant difference between all-finger flexion and index finger flexion, as well as between all-finger extension and index finger flexion.

In maximum dorsiflexion of the wrist, a significantly longer distance was observed in all-finger extension than those in all-finger flexion ($p = 0.00$) and index finger

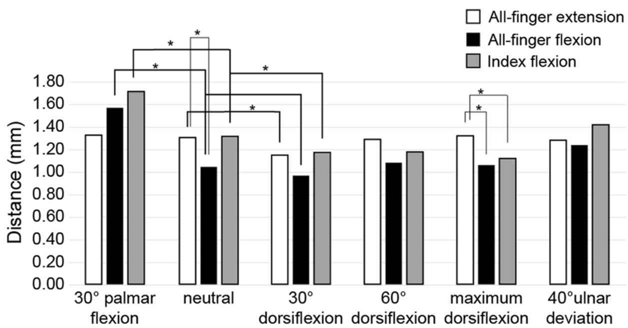

Fig. 4 Distance between the index flexor digitorum profundus and watershed line at various wrist positions with various finger positions. *$p<0.05$

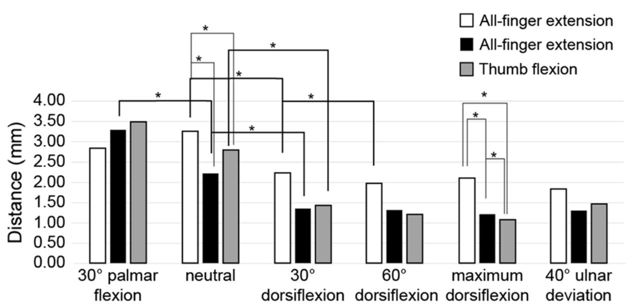

Fig. 5 Distance between the flexor pollicis longus and watershed line at various wrist positions with various finger positions in men. *$p<0.05$

flexion ($p=0.0025$), respectively. However, there was no significant difference between all-finger flexion and index finger flexion.

The distance between the FDP2 and distal radius tended to be shorter in all-finger flexion and index finger flexion than in all-finger extension in dorsiflexion of the wrist. When wrist dorsiflexion was > 30°, the distance between the FDP2 and distal radius did not significantly change. Finally, the distance between the FDP2 and distal radius was the shortest with all-finger flexion at 30° dorsiflexion of the wrist (Fig. 4).

Analyses based on sex

We performed separate examinations in men and women. The distance between the FPL and distal radius was the shortest in isolated thumb flexion in maximum dorsiflexion of the wrist. Conversely, the distance between the FDP2 and distal radius was the shortest in all-finger flexion in 30° dorsiflexion of the wrist. Their respective results were similar (Figs. 5, 6, 7, 8).

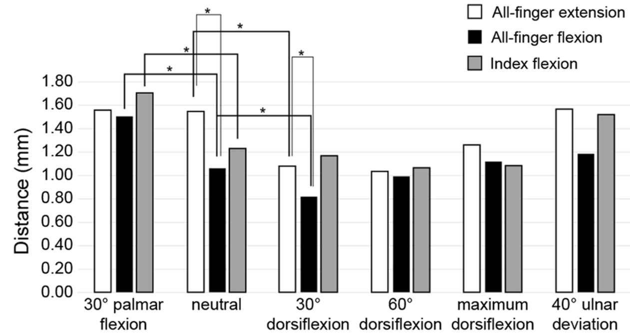

Fig. 6 Distance between the index flexor digitorum profundus and watershed line at various wrist positions with various finger positions in men. *$p<0.05$

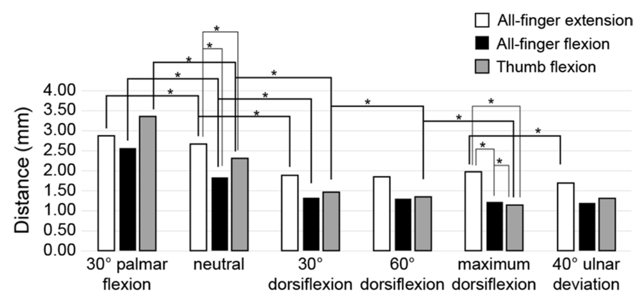

Fig. 7 Distance between the flexor pollicis longus and watershed line at various wrist positions with various finger positions in women. *$p<0.05$

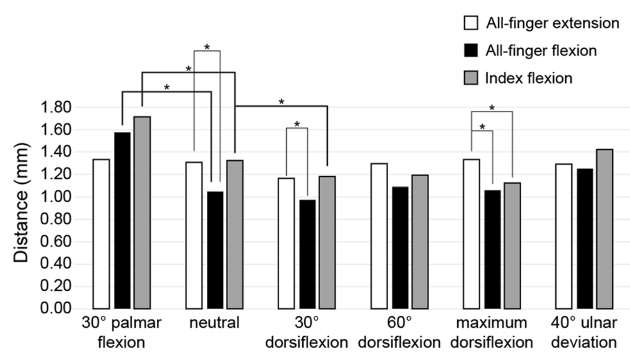

Fig. 8 Distance between the index flexor digitorum profundus and watershed line at various wrist positions with various finger positions in women. *$p<0.05$

Discussion

A volar locking plate is commonly used for unstable distal radius fractures as it enables stable fixation and early return to daily life [10, 11]; however, FPL and FDP2 ruptures have been reported as complications [9, 12–14].

FPL and FDP2 ruptures, such as extreme distal placement, screw head protrusion, insufficient reduction, or loss of reduction [8–15], are attributed to plate position. It is speculated that protrusion of the plate toward the volar side and distal placement of the plate beyond the watershed line may potentially irritate the flexor tendon; eventual rupture is often reported [8, 11–14]. Since the flexor tendons are closest to the bone and the plate at the watershed line, several papers have recommended placing the plate proximal to the watershed line to reduce the risk of tendon rupture [2, 7]. However, depending on the type of fracture, it is necessary to support the palmar side of the articular surface with the volar locking plate beyond the watershed line to fix fractures that may result in very small distal bone fragments and to stabilize crushed intra-articular fractures [6, 16].

Therefore, the scope for preventing tendinitis by reducing friction between the plate and tendon is limited [2, 6]. It is reported that FPL rupture will occur even when the low profile of the anatomic volar locking plate is improved and even if placement of the locking plate is addressed at the proximal position at the watershed line [9]. As a result, several studies recommend the early removal of the volar plate after radius fracture undergoes bone union [9, 11, 14, 17].

Elevation of the plate from the distal radius and distal placement of the plate over the watershed line is also risk factors for tendon rupture, but the correlation between the position of the plate and the FPL and FDP2 is unknown [2, 18]. Tanaka et al. [11] studied changes in fixation position of the locking plate at the distal radius in cadavers and measured the pressure on the FPL at 30° and 60° wrist dorsiflexion. They reported that the more distally the volar locking plate was located, the higher the pressure on the FPL. Although the study showed the risk of FPL rupture due to distal placement of the volar locking plate, its effect on finger movements and the surrounding soft tissue was not evaluated.

Several studies have been conducted on FPL rupture using ultrasonic examination, which enables noninvasive in vivo evaluation. Kara et al. [19] measured the distance between the FPL and volar rim, and reported shorter distances in asymptomatic synovitis of tendons on the affected side. However, these researchers did not discuss the effect of pronator quadratus (PQ) restoration, changes in the distance between the finger flexor tendon due to finger and wrist position, or variations due to wrist and finger movements. We believe that the existence of the PQ and intermediate fibrous zone at the distal radius is important for maintaining the distance between the FPL and distal radius. Several studies have stressed the importance of PQ restoration after locking plate fixation [12, 17]; however, some studies claim the opposite [20]. Therefore, PQ repair is controversial. However, many hand surgeons are currently restoring the PQ after volar locking plate fixation [21].

Nanno et al. [16] reported on the kinematics of the flexor tendons of the fingers, including the FPL, and also evaluated the positional relationship between the distal radius and FPL in five wrist positions (i.e., neutral, 10° radial deviation, 40° ulnar deviation, 60° dorsiflexion, and 60° palmar flexion) in all-finger extension, all-finger flexion, and thumb flexion using transverse ultrasonography. Nanno et al. showed that the positional relationship between the FPL and distal radius changed not only via wrist dorsiflexion, but also with finger movement. In addition, they indicated that the distance between the FPL and distal radius was the shortest in 60° dorsiflexion of the wrist with all-finger flexion. The finding that the distance between the FPL and distal radius is shorter in wrist dorsiflexion or thumb flexion in healthy volunteers is valuable. However, the study did not consider the fact that wrist dorsiflexion is sometimes > 60° during activities of daily living, such as pushing an object, supporting the body when standing up from a chair, stretching, and doing yoga. As such, we deemed it necessary to measure the distance between the flexor tendon and distal radius during > 60° wrist dorsiflexion.

The current study differs from the study by Nanno et al. in that the measurement in maximum wrist dorsiflexion was included during longitudinal ultrasonography. We measured both the distance between the FPL and distal radius and between the FDP2 and distal radius. When measuring the distance between the FPL and distal radius, our results were almost identical to those of Nanno et al., with the exception of maximum wrist dorsiflexion. The difference between our results and those of Nanno et al. was that, in our study, the shortest distance between the FPL and distal radius was seen in maximum wrist dorsiflexion with isolated thumb flexion. Nanno et al. reported that, in all-finger flexion, the FPL moved ulnodorsally, and the FDP and flexor digitorum superficialis (FDS) moved radiopalmarly. The reasons for the thumb flexion during maximal wrist dorsiflexion, which causes the shortest distance, are that the dorsal/palmar movements of the FPL, FDP, and FDS are restricted, and that the angle of maximum wrist dorsiflexion with all-finger flexion is smaller than that of isolated thumb flexion.

Even in all-finger extension, the distance between the FPL and distal radius becomes shorter in wrist dorsiflexion than in the neutral position. However, as the wrist dorsiflexion angle increases, the muscle component of the FPL covers more of the watershed line, which increases the distance between the FPL and distal radius (Fig. 2b, d). Similar to the FPL, the distance between the FDP2 and distal radius in all-finger extension increases as the wrist dorsiflexion angle increases, and the muscle component of the FDP2 increasingly covers the watershed line.

In the current study, in the 40° ulnar deviation of the wrist, the distance between the FPL and distal radius was almost the same as that in 60° wrist dorsiflexion; this finding was similar to the results obtained by Nanno et al. We believe that this occurred, because the FPL runs radially beyond the center of rotation (ulnar and radial deviations) of the wrist, based on which the traction of the FPL increases. In addition, the distance between the FDP2 and watershed line at 40° ulnar deviation was almost the same as that in the neutral position of the wrist. We thought that FDP2 traction did not occur, even if the wrist was in ulnar deviation due to the FDP2 running almost parallel to the center of rotation of the wrist. Nanno et al. reported that the locations of the FDP, FDS, and FPL changed according to the wrist and finger position. The distance between the FDP2 and distal radius was closest in 30° wrist dorsiflexion with all-finger flexion, which was thought to result from the involvement of the FDP, FDS, and FPL.

Regardless of all-finger extension, all-finger flexion, or index finger flexion, we believe that a better measurement occurred during > 30° wrist dorsiflexion, as there was no significant difference in the distance between the FDP2 and distal radius at that wrist position.

Our study has limitations. First, the sample size was small. If the sample size was larger, our findings would have been more extensive, leading to detailed results and definite conclusions. Second, since the custom-made splint that was holding the wrist in healthy subjects did not completely control the movement, the wrist may have loosened in the anteroposterior direction due to wrist rotation and flexion–extension of the fingers. Third, compared to transverse ultrasonography, it was difficult to hold the transducer on the flexor tendon during longitudinal ultrasonography at 90° to the forearm. In addition, the aim of the placement was not to push the subject's wrist too much, which could affect the measurement of the maximum diameter of the tendon. Successful visualization depends on the examiner's skill and experience, which were not tested or compared; we aim to include this factor in future studies.

Fourth, it is impossible to measure the distance between the flexor tendon and distal radius during > 30° wrist palmar flexion when using longitudinal ultrasound. Detailed results on measurements during palmar flexion have not been obtained, and we aim to include this factor in future research. Finally, our study was only conducted in healthy volunteers. The current study aimed to determine where the FPL and FDP2 would be closest to the radius in healthy subjects; therefore, we hypothesized that this measurement could be used to determine the ideal distance after volar locking plate fixation for distal radius fracture. We believe that this research generated a valuable foundation to prevent tendon rupture.

Conclusions

In summary, it is necessary to measure the distance between the FPL and distal radius in maximal wrist dorsiflexion with full flexion of the isolated thumb, as the shortest distance was observed with flexion of the isolated thumb. On the contrary, we recommend measuring the distance between the FDP2 and distal radius in 30° wrist dorsiflexion with flexion of all the fingers.

Compliance with ethical standards

Conflict of interest Kanta Imao, Hitoshi Miwa, Kazutoshi Watanabe, Tsuyoshi Satoh, Atsuki Sano, and Naoto Endo declare that they have no conflicts of interest.

Human rights statements This study was approved by the Institutional Review Board of our institution and all investigations were conducted in conformity with the ethical principles of research, as stated in the Declaration of Helsinki.

Informed consent The subjects who volunteered for this study were informed about the design of the study, including any potential risks and discomfort, and all of them provided written informed consent.

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