

Analysing orthotic designs for de Quervain's disease based on in vivo gliding distance of extensor pollicis brevis tendon

1. Introduction

In recent years, many studies have reported on the presence of a septum within the tendon sheath in the first compartment of the extensor tendon, and have interpreted pathology related to EPB tenosynovitis in terms of the etiology and diagnosis of de Quervain's disease.¹⁻³ As performing selective steroid injections into the EPB tendon sheath using triamcinolone acetonide, a steroid water-soluble suspension, has been shown to be a markedly effective treatment, some scientists are of the opinion that orthosis, which impair daily lifestyle, are unnecessary. However, recent meta-analyses of treatment effects have come to the consensus that the combined use of an appropriate orthosis with hand therapy leads to better treatment outcomes than steroid injections alone.⁴⁻⁶ In our previous research, conservative treatment involving fixation of the affected site with an orthosis has proven effective for immediate reduction of acute pain during the perinatal period in patients with de Quervain's disease, with subsequent continued use resulting in long-term pain relief.⁷ However, there have also been some refractory cases who responded poorly to conservative treatment and for whom it was difficult to achieve pain relief through fixation with a conventional thumb spica orthosis alone (Fig. 1). Going forward, identifying how best to treat these cases must be investigated.

2. Purpose of the Study

The purpose of this study is to reconsider the orthotic design used for de Quervain's disease based on *in vivo* information obtained from ultrasound images. In order to modify and further develop conventional orthoses to establish more effective hand orthoses based on etiology, disease features, and anatomical characteristics, we herein verify and discuss the anatomical findings that can be discerned from ultrasound images to reconsider the conservative treatment and to identify a method of orthosis utilization appropriate for the inflammatory phase.

3. Methods

3.1 Participants

Participants were given an explanation of the study outline before providing their informed consent. Participants comprised 20 healthy adult men and women (13 men, 7 women; age (mean \pm SD): 29.5 ± 4.7 years); 40 of their hands with no history of thumb injury or deformation were examined.

As an advanced screening test, participants were requested to engage in automatic thumb extension. After confirming EPB tendon relief through visual examination and palpation, the EPB tendon in the area from the dorsal base of the thumb proximal phalanx (PP) to the dorsal base of the distal phalanx (DP) was investigated using a linear probe. Doing this allowed us to evaluate anatomical variations in the EPB tendon insertion. We also confirmed the presence of a septum in the first compartment of the extensor tendon in all cases. As a result of screening, all cases of EPB tendon defect were excluded.

3.2 Methods

All procedures were performed in accordance to the ethical standards of the institutional and national ethics compliance committees, and the Declaration of Helsinki of 1975, as revised in 2008.

Before measurement, a probe was applied on the dorsal side of the first metacarpal bone of the subject to obtain a long-axis view, and gliding dynamics of the EPB tendon were observed after confirming the entire length of the EPB tendon from the proximal to peripheral sheath while taking care not to confuse gliding of the EPB and APL tendons.

Ultrasound diagnostic imaging equipment (ARIETTA 70; Hitachi Ltd., Tokyo, Japan) was used for measurement of *in vivo* gliding distance in the EPB tendon during thumb IP joint autonomic movement while wearing a thumb spica orthosis. With an 18MHz linear probe, tomographic ultrasound images were taken during autonomic movement of the thumbs. Recorded data were saved as AVI files on a hard disk drive (HDD) on the main computer unit. Next, using a two-dimensional tissue tracking (2DTT) system, we established three tomographic image initialization points for both the thumb carpometacarpal (CM) joint fissure gap (i.e., fixation point) and EPB tendon (i.e., movement point). The device automatically traced the selected initialization points according to pixel intensity distribution data per frame in order to quantitatively evaluate the distance between two points.

Using the 2DTT system, use of a pattern-matching technique on ultrasound images makes it possible to trace the same site on each image and thereby confirm the coordinates set as initialization points as well as calculate the strain and arbitrary distances between two points.

This pattern-matching technique involves first designating the site you wish to track before cutting out a small region that includes the designated site. Next, the region with the distribution pattern exhibiting the luminosity that is most similar to the cut-out region is tracked and

identified in the next frame. Repeating this tracking process in all frames allows discernment of the point's coordinates as it moves across the images. The distance between two points can be calculated from the chronological coordinates of the two points detected through tracking (Fig. 2). Although this technology was developed to measure and calculate wall thickness strain and wall thickness strain rate on myocardial contrast echocardiography footage, there have also been attempts in recent years to apply it to the dynamic observation and movement quantification of soft tissues such as muscles and tendons.⁸⁻¹⁰ When using this 2DTT technique, the first condition involves setting an appropriate angle of view (i.e., within a range in which a high frame rate that exceeds a certain threshold can be achieved) and clearly recording tomographic images. In the present study, the frame rate was set at 42 frames/s.

The measured limb position was fixated with the wrist and thumb in an arbitrary position by fitting a thumb spica orthosis that is conventionally prescribed for conservative treatment of de Quervain's disease with the aim of increasing probe operability during thumb movement and research reproducibility. The wrist was fixated at a functional limb position of 20° dorsiflexion. Taking office work such as writing and computer usage into account, thumb position was fixated with the thumb CM joint in a slightly opposing position (30° palmar abduction, 30° radial abduction) and the thumb metacarpophalangeal (MP) joint flexed at 30°.

Participants were fitted with a thumb spica orthosis with their wrist and thumb fixated in the aforementioned positions. The starting position was maximum extension of the thumb IP joint. After maximum bending of the thumb IP joint from this position with autonomic movement, the thumb IP joint was then extended as far as possible with automatic movement. These movements were repeated over a 3-s measurement period, during which gliding dynamics were recorded. Next, thumb MP joint fixation was removed and maximum extension of the thumb MP and IP

joints were used as starting points so that participants could perform maximum bending of the thumb before extending it as far as possible. As per the previous measurement, gliding dynamics were recorded.

To reduce measurement error, the measurements were repeated three times consecutive thumb maximum bending and extension movements. The maximum gliding distance value between the points was adopted and mean values were used for analysis.

3.3 Operating Procedure

To increase test reproducibility, we hereby describe the operating procedure of the device used in this study (ARIETTA 70). The device was initialized and after entering the participant ID, the probe and “current view” command were selected. The probe was applied to the relevant site and EPB tendon gliding dynamics were observed. Next, images were rendered, ensuring the inclusion of EPB tendon gliding with the thumb CM joint; 3 s of gliding dynamics were saved in a HDD in the main unit. Next, the “2DTT analysis” command was selected as an application tool and three initialization points for both the fixation point on the joint surface of the thumb CM joint fissure gap and the EPB tendon (i.e., movement side) were marked. In addition, the “process” command was selected and tracking footage between each point was confirmed with the pattern-matching technique in order to select the movement point determined to have been most closely tracked. Finally, “cine memory” command was selected on the “distance” measurement screen, the point that moved the farthest distance in the long-axis direction was selected and the movement distance between two different points was determined as a measure of gliding distance. These operations were performed three times on each hand.

3.4 Data Analysis

To analyze the obtained data, an unpaired t-test was used to compare EPB tendon gliding distance between two groups. The groups were divided based on EPB tendon anatomical insertion point: a non-variation group of EPBs with a typical textbook insertion point (dorsal side of thumb PP base) with no variation, and a variation group of EPBs with anatomical variation whereby the insertion point extends to the dorsal side of the thumb DP base. The condition “presence or absence of a septum” was added to the two groups; accordingly, gliding distance was compared across the four groups using Tukey’s multiple comparison test. Gliding distance was compared between both hands of the same subject using Wilcoxon’s test. EPB tendon gliding distances during thumb IP joint autonomic movement between the non-variation and variation groups were compared using the Shapiro-Wilk normality test. A statistical processing software (R version 2.8.1) was used for data analysis and the level of statistical significance was set at 5%.

4. Results

In the present study, we encountered difficulties quantifying tendon gliding distance due to performance limitations of the ultrasound diagnostic imaging equipment. Tendon components are composed of multiple layers of collagen fiber bundles on the long axis, causing them to be rendered as a particular fibrillar pattern on images. This meant that even with appropriate frame and contrast intensity correction, there were cases in which the initialization points on images could not be tracked. Therefore, to evaluate tendon gliding in the long-axis direction, we searched for regions that could be clearly differentiated in the middle of the screen and did not

protrude out of frames, and carefully marked these. As the examiner was obligated to continue rendering images of the moving target while assuring that they never moved out of the frame, advanced probing operation capabilities were required. The extensor tendons, in particular, do not have a ligamentous sheath; consequently, height disparities such as lifting and sinking can occur in addition to linear movement. The tester must therefore be cautious of these factors while performing accurate tracking.

Advanced screening results indicated that EPB tendon variation was observed in 9 (22.5%) of the 40 hands. The variation group comprised four men and one woman, with a mean age of 30.8 ± 4.7 years. In these participants, examination of the peripheral direction of the EPB tendon using a linear probe confirmed that the funicular slip continued from the EPB tendon in the dorsal side of the thumb DP base from the thumb PP dorsal side distal point (Fig. 3 and 4). No variation at the site of EPB tendon insertion was noted in 31 (77.5%) of 40 hands. The non-variation group included ten men and six women, with a mean age of 28.9 ± 4.6 years. A septum was noted in the extensor tendon first compartment in 23 (57.5%) of 40 hands. Table 1 shows participant characteristics according to the presence or absence of anatomical variations of the EPB tendon and the presence or absence of a septum. We also found intra-individual physical diversity, as thickness of tendon substance differed between the left and right hands in some participants, with some exhibiting very thin EPB tendon thickness on one side and subsequent poor gliding.

Mean EPB tendon *in vivo* gliding distance during autonomic movement of the thumb IP joint was 3.22 ± 0.55 mm in the variation group and 1.49 ± 0.56 mm in the non-variation group. Moreover, mean gliding distances in the four groups divided according to the presence or absence of variations and/or septa were 3.44 ± 0.54 mm in the variation + septum group (6

hands; 15%), 2.77 ± 0.27 mm in the variation + no septum group (3 hands; 7.5%), 1.52 ± 0.53 mm in the non-variation + septum group (17 hands, 42.5%), and 1.45 ± 0.61 in the non-variation + no septum group (14 hands; 35%). Thus, even with the limb externally fixated using a conventional thumb spica orthosis, we were able to confirm *in vivo* gliding of the EPB tendon accompanying thumb IP joint movement. We also observed some intra-individual differences in this gliding distance. In terms of EPB tendon gliding distances during thumb IP joint autonomic movement, results demonstrated that neither the variation or non-variation groups exhibited normal distribution or equal variance, and t-testing of the two samples indicated a significant difference between the two ($p < 0.01$). Moreover, comparison of gliding distance in the aforementioned four groups divided by the presence or absence of variations and/or septa using the Shapiro-Wilk test showed that all p-values were ≥ 0.05 , indicating normal distribution. In addition, the Levene's test p-value was ≥ 0.05 , indicating equal variance. Therefore, one-way analysis of variance was performed and a significant difference was noted. Based on this, we performed multiple comparison using Tukey's test. Subsequent results showed that regardless of the presence or absence of a septum, a statistically significant difference in gliding distance was observed between the variation and non-variation groups (Fig. 5). The results of Wilkinson's test comparing gliding distance between hands in the same participants revealed no significant differences ($p = 0.78$).

Next, we removed the thumb MP joint fixation and measured EPB tendon *in vivo* gliding distance during simultaneous movement of the thumb IP and MP joint. Mean distances were 3.72 ± 0.79 mm in the variation group and 2.40 ± 0.90 mm in the non-variation group. Moreover, gliding distances in the four groups divided according to the presence or absence of variations and/or septa were 3.87 ± 0.83 mm in the variation + septum group (6 hands; 15%), 3.48 ± 0.95

mm in the variation + no septum group (3 hands; 7.5%), 2.59 ± 1.10 mm in the non-variation + septum group (17 hands, 42.5%), and 1.78 ± 0.80 in the non-variation + no septum group (14 hands; 35%). Results of Tukey's test indicated that regardless of the presence or absence of septa, a significant difference was noted in gliding distance between the variation and non-variation groups (Fig. 6). Table 2 shows the results of comparison of mean gliding distance of the EPB tendon during thumb movement across the four groups.

5. Discussion

Anatomical variations of the EPB and APL tendons are important factors when considering thumb fixation range. Extremely diverse anatomical findings have been reported for variations of both tendons in the extensor tendon first dorsal compartment. These include cases of EPB tendon defect, cases with two or more APL tendons, and cases in which a septum envelopes both tendons.¹¹ Because such anatomical variations within the narrow tendon sheath also represent factors that can cause mechanical stress, the affected site must be fixated with casting while taking the course of both tendons into account. In addition, the notable anatomical variations observed in our study were variations in EPB tendon entheses.^{12,13} Normally, the extensor pollicis longus (EPL) and EPB tendons run toward the peripheries and converge at the thumb PP dorsal side. On an insertion point level, part of the EPB tendon normally runs into the EPL tendon.¹⁴ Thus, it was suggested that both tendons may exhibit fibrous connections at the insertion point. Examining previous studies that have focused on anatomical findings related to this variation, Alemohammad et al.¹⁵ surveyed 90 cadaver hands and 143 postoperative cases of de Quervain's disease. They reported EPB variations in the form of EPB defects and various other pattern

specificities, such as cases in which the tendon passed through the PP dorsal side and stopped in the dorsal side of the thumb DP base (as has been observed in EPL tendons) and cases in which the tendon stopped in the DP after becoming impacted in the extensor hood of the thumb PP dorsal side. These EPB variations were more common in cases of de Quervain's disease than in cadaver hands, suggesting that EPBs with a septum act in a complementary manner of EPL during thumb IP joint extension movement. In terms of the anatomical variation patterns in EPB tendon insertion points, Kulshreshtha et al.¹⁶ performed a cadaveric study of 44 hands and found that in approximately half of cases, the EPB tendon was partially attached to the PP and extensor hood and joined the EPL tendon to attach to the DP. They reported a much higher variation rate than those reported by Dawson et al.¹⁷ and Brunelli et al.¹⁸ Further, Jackson et al.¹⁹ reported the anatomical results of 300 hands, finding that the EPBs of 57 hands had two insertion points and that one slip attached to the PP; whereas, the other became tangled with the EPL tendon to travel toward the DP, and that in 16 hands the EPB acted on thumb IP joint extension. Thus, the EPB not only acts as the main operation muscle in thumb MP joint extension, but has also been shown in previous studies to act on thumb IP joint extension movement as a complementary muscle to the EPL. In our study of *in vivo* gliding distance, we confirmed the elongation of tissue that had commingled with the extensor hood and EPL tendon during bending of the thumb IP joint.

Conversely, we confirmed the occurrence of proximal gliding, which was enhanced and modified by EPL muscle activity, during thumb IP joint extension. Thus, thumb IP joint autonomic movement may be a factor causing gliding resistance in the first dorsal compartment of thickened extensor tendons.

When externally fixating the affected site, consideration must also be paid to activity of the EPL, which is a synergistic muscle with the EPB and APL, from the viewpoint of suppressing thumb

muscle activity. The EPL is anatomically characterized by its muscular component being adjacent to the APL in the interosseous membrane of the ulna bone, which comprises its origin. Both muscles, which are involved in the joint movement pattern of extension and abduction, are likely to exhibit cooperative contraction during purposive movement of the thumb. Moreover, although rare, some anatomically abnormal cases in which part of the EPB tendon was derived from the APL muscle belly have been reported.¹³ Simultaneous APL contraction accompanying EPL muscle activity may thus result in proximal direction gliding of both the EPB and APL tendons in the extensor tendon first dorsal compartment.

Conventional thumb spica orthosis do not restrict movement of the thumb IP joint. However, we were able to confirm the EPB complementary action observed during the *in vivo* thumb IP joint extension movement while participants were wearing conventional thumb spica orthosis.²⁰

Therefore, it is necessary to evaluate physical characteristics such as septa and anatomical variations based on advanced screening with ultrasound examinations before considering thumb fixation range for patients in the acute inflammation phase or those exhibiting recurrence.

5.1 Limitations

In the present study, we were able to confirm that this technique was a beneficial method for measuring the distance between two moving points. However, as the 2DTT application used in the present study was developed as a measurement tool for echocardiography footage, few previous studies have examined its application for the measurement of motor organs such as muscles, tendons, and ligaments. In *in vivo* situations, tendon gliding needs to be evaluated not only two-dimensionally on a flat plane but also in light of three-dimensional space elements such

as depth and height. Keeping this point in mind, two-dimensional gliding evaluation using the 2DTT method should be performed. Going forward, it is anticipated that improvement of the reproducibility and accuracy of this test will not only contribute to the understanding of various disease structures, but will also make it possible to apply the technique widely in the rehabilitation field. The technique described herein is considered useful for identifying sites of adhesion after tenosuture and for the quantitative evaluation of tendon gliding ability. Therefore, hand therapists need to be highly knowledgeable and skillful with regards to ultrasound testing as an assistive diagnostic technique.

6. Conclusions

We used cutting-edge ultrasound diagnostic imaging equipment to observe gliding dynamics of the EPB tendon during thumb IP joint autonomic movement and to measure gliding distance. We were able to confirm gliding of the EPB tendon in the proximal direction as a complementary action to enhance EPL contraction during autonomic extension of the thumb IP joint. Tendon distal gliding arose with bending of the thumb IP joint not only in EPB tendons with clear anatomical variations such as an insertion point in the DP, but also in EPB tendons with conventional textbook insertion points. When introducing external fixation such as orthosis to cases with prolonged pain or de Quervain's disease in the acute inflammatory phase, the thumb fixation range should be considered based on the results of advanced ultrasound screening.

Acknowledgements

We would like to extend our deepest gratitude to Dr. Koichi Sairyo, professor of Orthopedic Surgery of the Division of Medical Research at the Tokushima University Graduate School of Biomedical Sciences, for offering considerable cooperation and advice when implementing this study and writing the report, to everyone at the Department of Rehabilitation, Kaisei General Hospital who supported us daily in clinical activities and research, and to everyone at the Hitachi Healthcare Takamatsu First Sales Office who cooperated in providing research devices.

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Figure 1. Conventional thumb spica orthosis

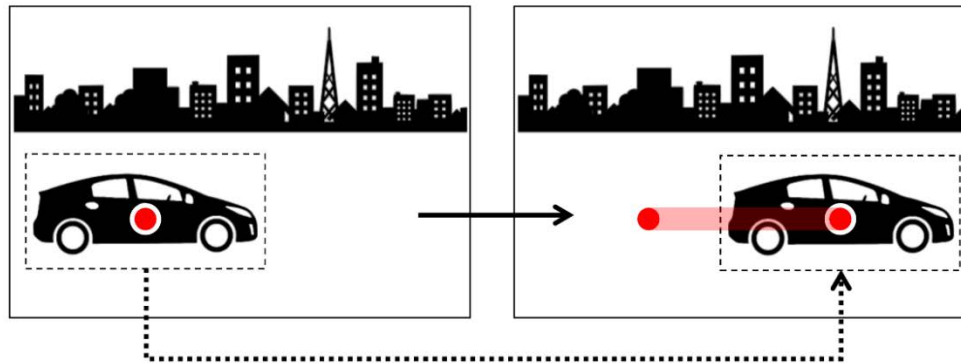
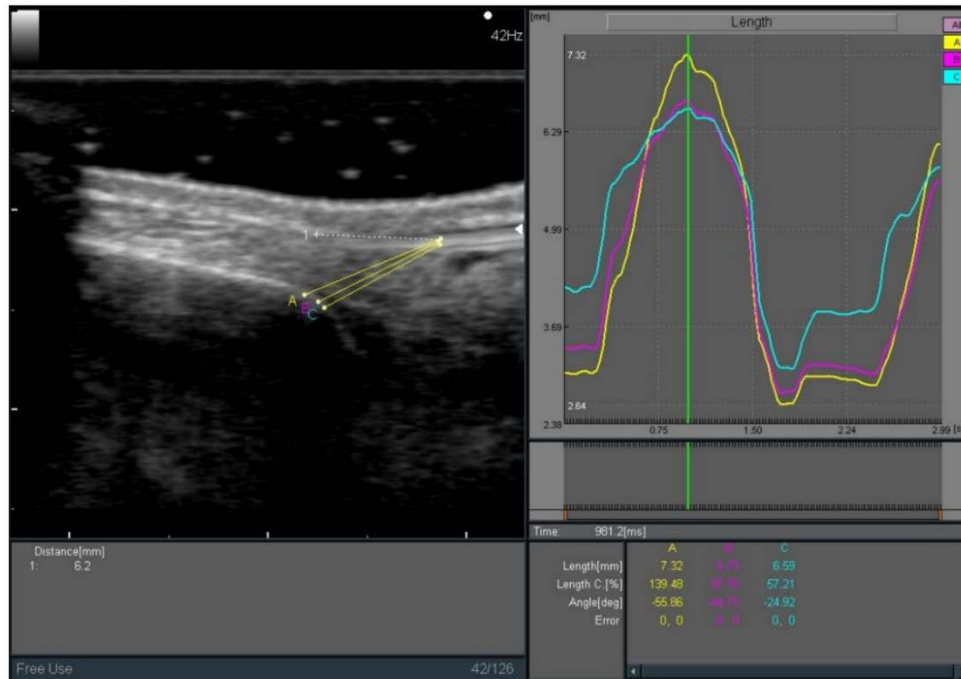


Figure 2. Pattern matching technique

A section of the image containing the tracking point is cut out, and the region closest to the image cut-out is identified in the next frame. Then, the site to which the tracking point moved is calculated.

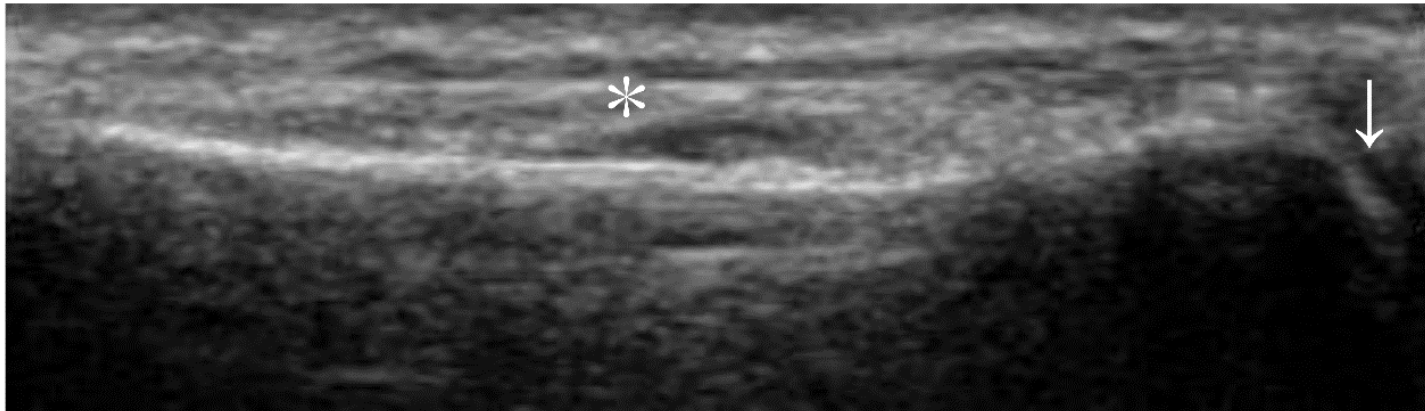


Figure 3. Anatomical variation case: long-axis view of the thumb PP radial dorsal side. *: Funicular tissue that extends from the extensor pollicis brevis tendon to the distal phalanx; → (arrow): thumb IP joint fissure gap .

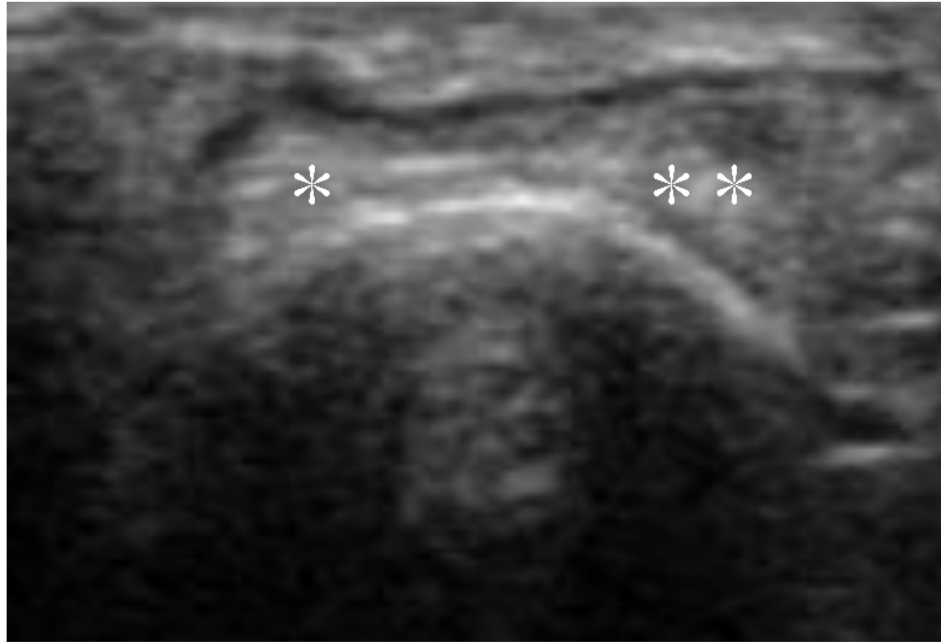


Figure 4. Anatomical variation case: short axis view of the thumb PP dorsal side distal part.*: Extensor pollicis brevis tendon; **: Extensor pollicis longus tendon

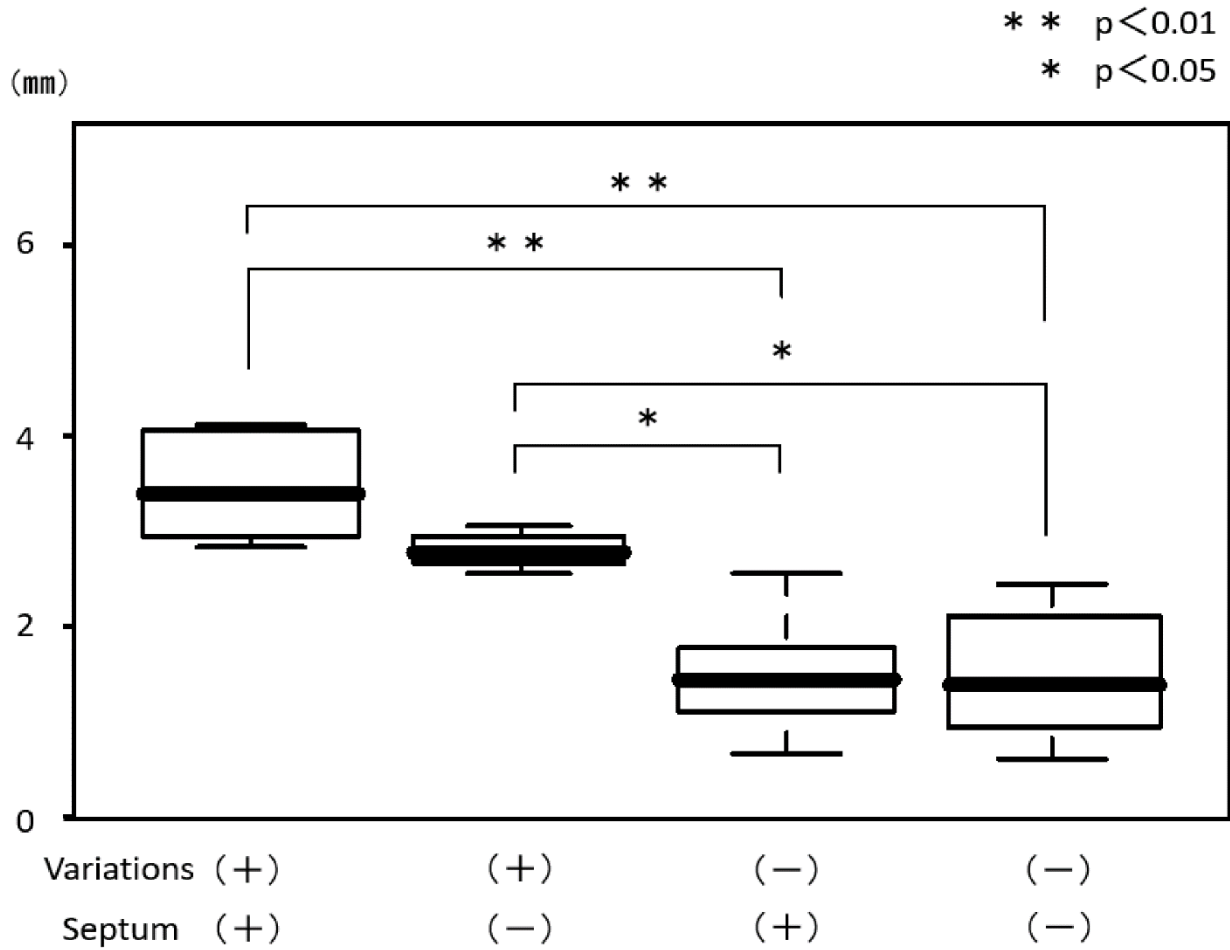


Figure 5. Extensor pollicis brevis tendon *in vivo* gliding distance (mm) in autonomic movement of the thumb IP joint across four groups divided by presence/absence of variations and septa

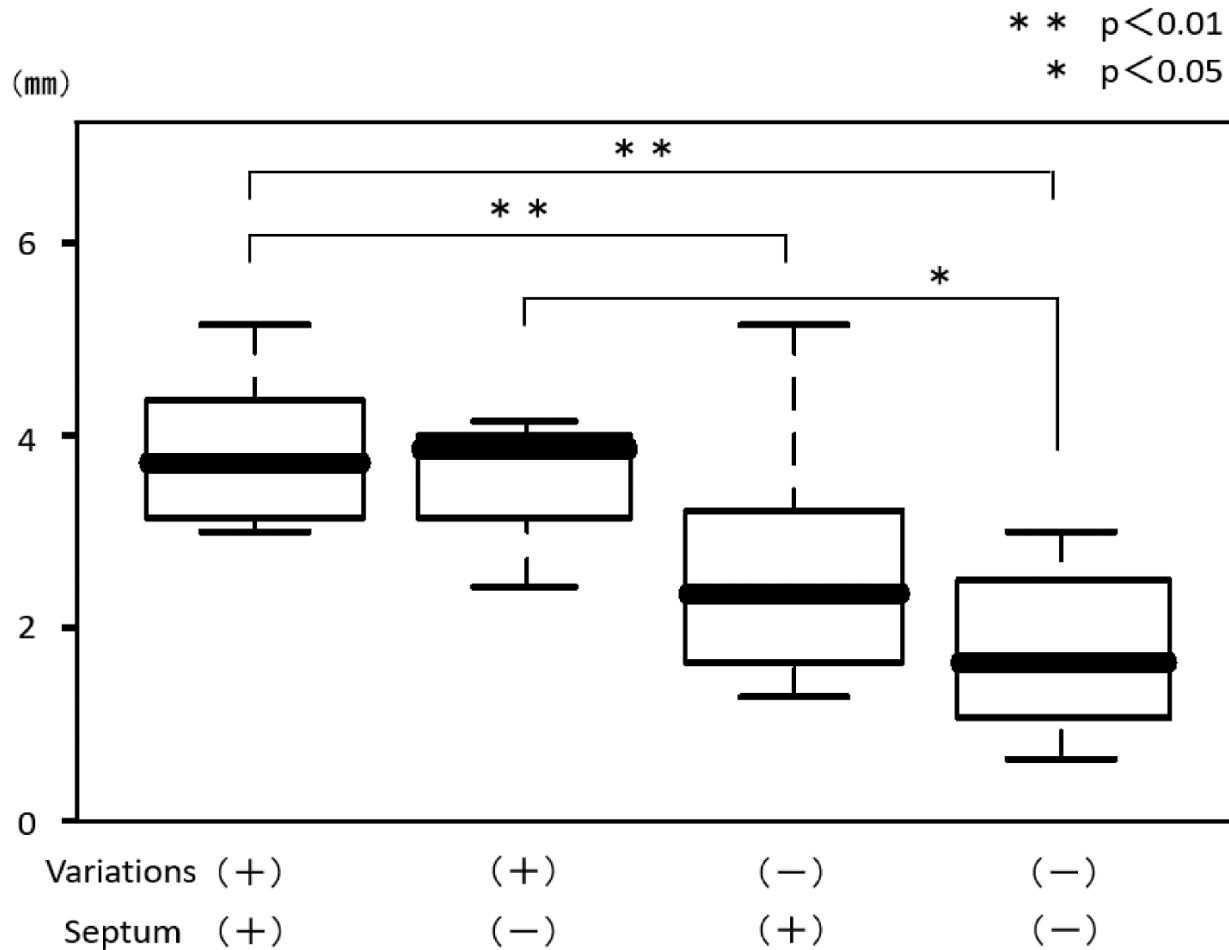


Figure 6. Extensor pollicis brevis tendon *in vivo* gliding distance (mm) in autonomic movement of the thumb interphalangeal/metacarpophalangeal joints across four groups divided by presence/absence of variations and septa

Table 1. Participant characteristics (n = 40)

Presence of septum, +; absence of septum, -; a variation group of EPBs with anatomical mutation whereby the insertion point extends to the DP dorsal side base, +; a non variation group of EPBs with a typical textbook insertion point extends to dorsal side of thumb PP base, -

		Septum	
		+	-
Anatomical variation	+	6 (15%)	3 (7.5%)
	-	17 (42.5%)	14 (35%)

Table 2. Mean gliding distance (mm) of extensor pollicis brevis tendon during autonomic movement of the thumb interphalangeal/metacarpophalangeal joints across four groups divided by presence/absence of variations and septa

		Thumb IP joint		Thumb IP / MP joint	
		Septum			
		+	-	+	-
Anatomical variations	+	3.44 ± 0.54	2.77 ± 0.27	3.87 ± 0.83	3.48 ± 0.95
	-	1.52 ± 0.53	1.45 ± 0.61	2.59 ± 1.10	1.78 ± 0.80