



Sonographic morphometry of abductor pollicis brevis: can direct contact yield images comparable with those obtained by the water bath technique?

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Abstract

Purpose This study sought to compare ultrasound-guided measurements of the abductor pollicis brevis (APB) using the water bath technique (WBT) and the direct contact method (DM) and investigate whether the DM can reproduce the measurements that would be obtained with a non-contact method, such as the WBT.

Methods The APB muscles of 80 hands (40 healthy adults) were measured. The WBT was performed in a plastic container filled with water. The probe was placed adjacent to the skin surface without contact. In the DM, sonographic images were obtained with the probe and skin separated by sufficient transmission gel. The muscle thickness and cross-sectional area (CSA) were calculated with both methods. All subjects were examined three times by two examiners to estimate the inter- and intra-observer reliability. Bland–Altman analysis was performed to examine the agreement between the methods.

Results No significant differences in the thickness or CSA of the APB were found. The interclass correlation coefficients for the WBT and DM showed almost perfect intra- and inter-observer reliability (range 0.87–0.94). There was no systematic bias between the techniques in the Bland–Altman analysis.

Conclusion Similar to the WBT, the DM provides measurements of the APB thickness and CSA without causing morphometric changes.

Keywords Abductor pollicis brevis · Carpal tunnel syndrome · Ultrasound · Water bath

Introduction

Atrophy of the abductor pollicis brevis (APB) is frequently recognized in carpal tunnel syndrome (CTS) associated with median nerve neuropathy [1]. Because the APB plays a key role in thumb motion [2, 3], weakness of the APB can cause severe hand dysfunction. When determining the severity of CTS, it is important to evaluate muscle atrophy of the APB, but to date this has been mainly assessed by subjective visualization [4, 5].

As a result of advances in ultrasound imaging, several studies have shown the utility of sonographic evaluation of the APB [6–8]. However, muscles close to the surface of the skin, such as the APB, are convex and soft, and their

morphometry tends to be altered when a probe is applied (direct contact method; DM). Previous reports have indicated that the curved surface of the hand results in suboptimal contact between the probe and the skin [9, 10]. Yet, the water bath technique (WBT) can provide images using a probe without touching the skin. Hence, some studies have indicated that the WBT better preserves the morphometry of the underlying musculature as compared with the DM [9, 10]. However, the DM is commonly used in the clinical setting, and it remains unclear whether the images and measurements of the underlying muscles accurately reflect the muscle, as would be determined using the WBT. Recent reports have indicated some of the technical tips associated with probe use in the sonographic examination of the APB thickness and cross-sectional area (CSA), ensuring that it is placed lightly on the skin [6] or placed onto the skin using sufficient transmission gel to avoid causing morphometric changes [7]. However, it remains unclear whether the DM can be used to measure the thickness and CSA of a muscle such as the APB with the same accuracy as those

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measurements taken with the WBT. Therefore, the purpose of this study was to investigate whether the DM can reproduce the measurements that would be obtained with a non-contact method, such as the WBT.

Materials and methods

Participants

Our Institutional Review Board approved this study, and all participants provided written informed consent before participating. Forty healthy adults (19 men and 21 women, mean age: 37.8 years, range: 23–56 years) participated in this study. Exclusion criteria were pregnancy, history of peripheral neuropathy, cervical radiculopathy, cerebral vascular disorder, hypothyroidism, diabetes mellitus, rheumatoid arthritis, and severe hand trauma.

Ultrasound evaluation

Ultrasound was conducted using B-mode US equipment (Aplio MX SSA-780A; Toshiba Medical Systems Corporation, Otawara, Japan) with a linear probe (6.2–12 MHz).

The WBT was carried out in a plastic container filled with water. The temperature of the water was measured and adjusted to approximately 32°C. The subject was placed in a relaxed sitting position with elbow in 90° flexion, forearm in 90° supination, the hand in neutral position, and the thumb held in maximum radial abduction. The thenar muscles were imaged inside the container. Before measuring, a line was marked between the radial sesamoid bone of the thumb and the scaphoid tuberosity. These bony landmarks could be easily identified by palpation as well as being confirmed by ultrasound. The line is between one of the origin

and insertion of the APB [11]. An axial image was then acquired at the midpoint of the line (see Fig. 1). The probe was placed as perpendicular as possible to the flexor pollicis longus, according to the method of Kim et al. [12]. In ultrasound evaluation by WBT, the probe was covered with a transparent thin cover and placed adjacent to the skin surface without contact.

The DM was carried out with sufficient transmission gel, particularly at both ends of the probe, because of the convex surface of the APB. The gel temperature was approximately 32°C, and the probe was placed on the skin with minimal pressure (Fig. 2).

The thickness and CSA of the APB were calculated with the measurement function of the ultrasound device. In the transverse image, the APB thickness was calculated on the perpendicular line of the most volar point of the first metacarpal bone. The APB-CSA was measured simultaneously in the image (Fig. 3). All ultrasound measurements were conducted bilaterally.

Two examiners (KF and KO) performed ultrasonography examinations. Both examiners had a comprehensive understanding of hand anatomy (graduate student majoring in hand surgery and certified hand surgeon, respectively). Examinations were conducted three times per subject at a minimum interval of 1 week by both examiners. The inter- and intra-observer reliability were estimated.

To compare the distance between the probe and the skin surface, the shortest distance between the upper edge of the image and the skin surface was measured on the images for both methods.

Statistical analysis

Data were presented as the mean and standard deviation (SD) for continuous variables. SPSS version 22 (IBM

Fig. 1 Ultrasound measuring method. **a** Water bath technique was carried out in a plastic container filled with water over the top of the thenar muscles. The Direct-contact method was carried out in the same container without water. **b** A line was marked between the radial sesamoid bone of the thumb and the scaphoid tuberosity (black dots) and a perpendicular bisector of the line. Axial imaging was acquired at the midpoint of the line

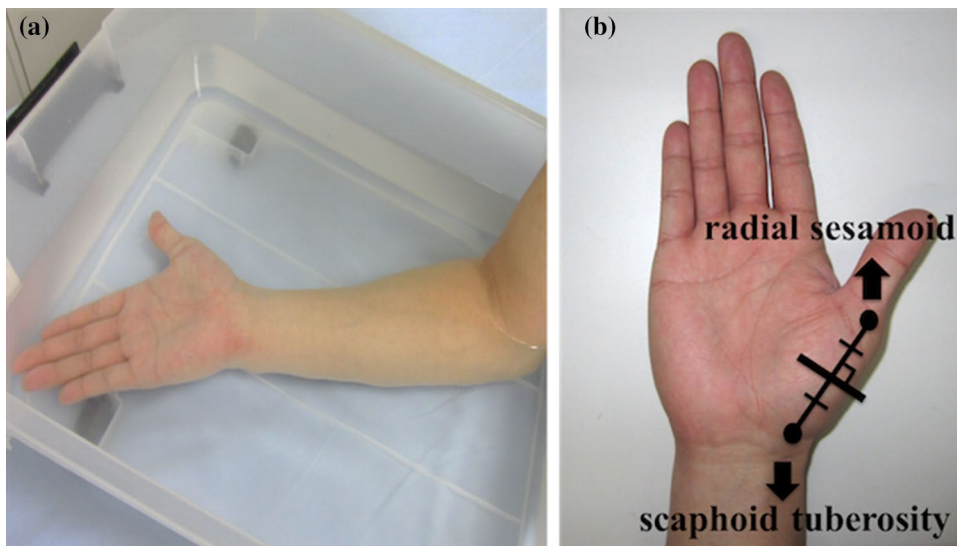


Fig. 2 Water bath technique (a, b): The linear array probe was adjusted without making contact with the skin in a plastic container filled with water. Direct-contact method (c, d): Sufficient transmission gel (black arrows) was used to avoid making contact with the skin

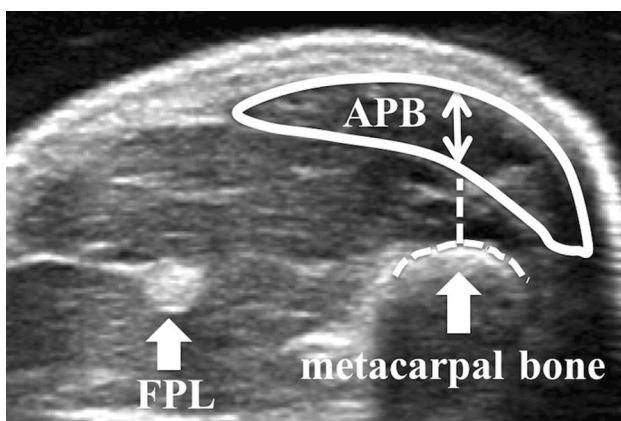
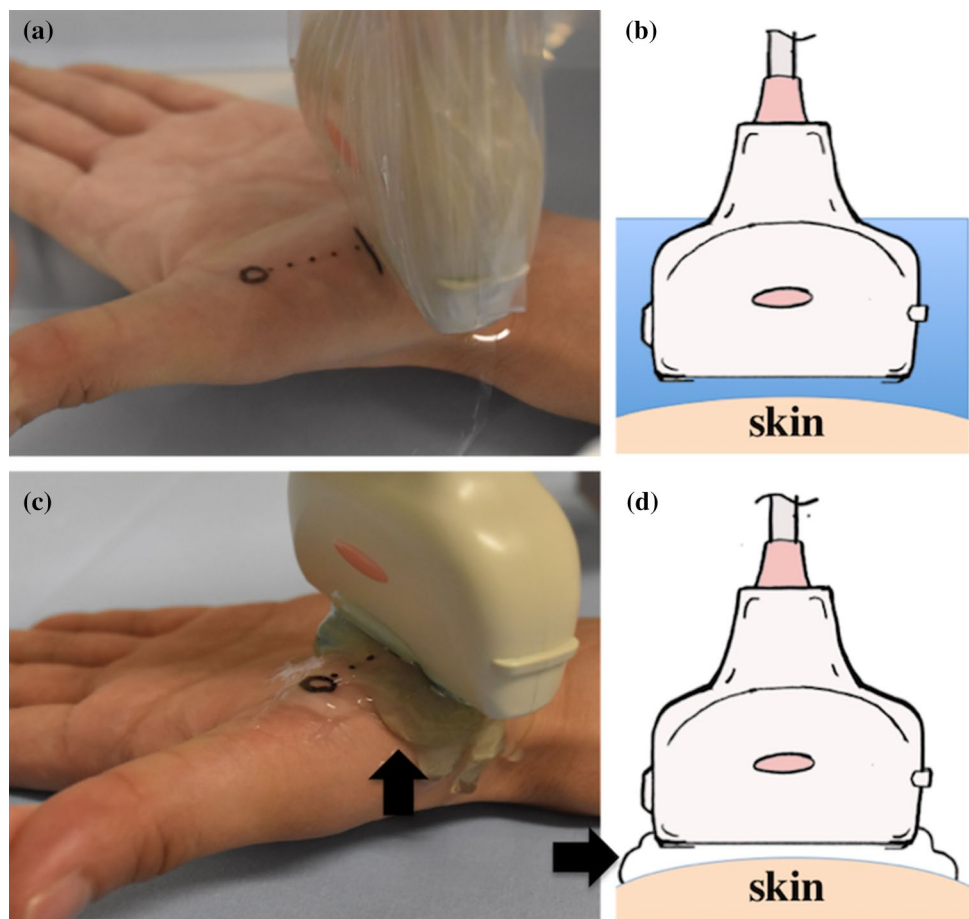


Fig. 3 Ultrasound image of the thickness and cross-sectional area (CSA) of abductor pollicis brevis (APB). The probe was adjusted so that the flexor pollicis longus (FPL) was seen in high brightness during axial imaging. APB thickness was calculated at the line of the most volar point of the first metacarpal bone (white arrow). CSA was calculated simultaneously (white outline)

Corporation, Armonk, NY) was used for all statistical analysis. The Pearson correlation coefficient (r) was evaluated to determine the correlation between WBT and DM measurements of APB thickness and CSA. Positive r values were

classified as no correlation (0.00–0.19), weak correlation (0.20–0.39), moderate correlation (0.40–0.59), strong correlation (0.60–0.79), and very strong correlation (0.80–1.00) [13]. The interclass correlation coefficients (ICCs) were calculated to estimate the inter- and intra-observer reliability between the two methods in the measurements of APB thickness and CSA. ICC values were classified as poor ($\text{ICC} \leq 0.00$), slight (0.01–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80), and almost perfect (0.81–1.00) [14]. ICC values were considered to be significant when the upper and lower boundaries of the 95% confidence intervals did not overlap [15]. Bland–Altman plots were used to analyze the absolute agreement between the measurements of the WBT and the DM. The 95% limit of agreement was defined as the mean difference $\pm 1.96 \times$ standard deviation [16].

Results

We found no significant difference in the mean \pm SD of APB thickness and CSA between the WBT and the DM. There were very strong positive correlations between the two methods ($r=0.96$ – 0.97 , $P < 0.01$) (Table 1).

Table 1 Thickness and cross-sectional area of the abductor pollicis brevis and correlation between the direct-contact method and the water bath technique

Parameter	DM	WBT	<i>r</i> Value
Observer 1			
APB thickness (mm)	5.75 ± 0.67	5.80 ± 0.68	0.97*
APB CSA (cm ²)	0.86 ± 0.14	0.87 ± 0.14	0.97*
Observer 2			
APB thickness (mm)	5.77 ± 0.68	5.82 ± 0.68	0.96*
APB CSA (cm ²)	0.86 ± 0.14	0.87 ± 0.14	0.96*

No significant difference was recognized between the WBT and DM. Data are presented as mean ± standard deviation. *r* value is presented as the Pearson correlation (**P* value < 0.01).

APB Abductor pollicis brevis, CSA cross-sectional area, DM direct contact method, WBT water bath technique

The inter- and intra-observer reliability of APB thickness and CSA by both methods was almost perfect reliability (ICC range: 0.87–0.94). There was no significant difference in the ICC values between the WBT and the DM (Tables 2, 3).

The Bland–Altman analysis showed that, relative to measurements taken using the DM, the WBT overestimated the thickness by an average of 0.05 mm, with 95% limits of agreement of – 0.33 to 0.43 mm. Likewise, the CSA was slightly larger with the WBT, with WBT overestimating CSA by an average of 0.01 cm², with 95% limits of agreement of – 0.06 to 0.09 cm² (Fig. 4). No systematic bias was found for either technique.

Finally, we measured the distance between the upper edge of the image and the skin surface using both methods. The distance with the DM was 2.03 ± 0.82 mm, whereas

Table 2 Intra-observer reliability of the measurement in the thickness and cross-sectional area of the abductor pollicis brevis

Parameter	DM	WBT	Significance of change
Observer 1			
APB thickness	0.89 [0.85–0.93]	0.92 [0.88–0.94]	NS
APB CSA	0.94 [0.91–0.97]	0.93 [0.90–0.95]	NS
Observer 2			
APB thickness	0.87 [0.82–0.91]	0.90 [0.86–0.93]	NS
APB CSA	0.93 [0.93–0.98]	0.94 [0.92–0.96]	NS

Data are interclass correlation coefficient (ICC) values (95% confidence intervals)

ICC showed almost perfect intra-observer reliability. Reliability between WBT and DM was not significantly different

APB Abductor pollicis brevis, CSA cross-sectional area, DM direct contact method, WBT water bath technique, NS not significant

Table 3 Inter-observer reliability of the measurement in abductor pollicis brevis thickness and cross-sectional area

Parameter	DM	WBT	Significance of change
APB thickness	0.92 [0.87–0.93]	0.94 [0.90–0.96]	NS
APB CSA	0.93 [0.90–0.95]	0.96 [0.93–0.97]	NS

Data are the interclass correlation coefficient (ICC) values (95% confidence intervals)

ICC showed almost perfect inter-observer reliability. Reliability between WBT and DM was not significantly different

APB Abductor pollicis brevis, CSA cross-sectional area, DM direct contact method, WBT water bath technique, NS not significant

the distance with the WBT was 2.06 ± 0.85 mm, with no significant difference observed (*P* = 0.88).

Discussion

The purpose of this study was to investigate whether the DM can reproduce the measurements of APB thickness and CSA that would be obtained with the WBT. We performed a sonographic evaluation of the APB to compare the reliability and validity of the two methods in terms of measurements of the muscle. We found no significant difference in the measurements of APB thickness or CSA between the WBT and the DM, with a very strong positive correlation between the two techniques. The ICC was almost perfect for the inter- and intra-observer reliabilities. There was also no systematic bias, as analyzed using the Bland–Altman method.

Ultrasound studies of CTS often focus on the morphometry or stiffness of the median nerve [17, 18]. Only a few ultrasound studies have focused on changes in muscle thickness or the CSA in patients with CTS [6–8]. Approximately 95% of the APB is innervated by the median nerve [11], and, therefore, this muscle is the earliest muscle among the thenar muscles to be affected in patients with CTS [1]. Hence, a quantitative evaluation of the APB via ultrasound could provide meaningful information for patients with CTS. Some studies that have used ultrasound to evaluate APB thickness and/or CSA in healthy volunteers have shown almost perfect inter- and intra-observer reliability when using the DM [6, 7]. Here, we similarly showed almost perfect inter- and intra-observer reliability for measurements of the APB with the DM.

Previous studies have emphasized the importance of paying attention to the probe as it contacts the skin, as the pressure causes morphometric changes to the underlying structures, including the muscle and its fascia. For example, Ishida et al. [19] reported that the pressure of the probe influenced the thickness of abdominal muscles evaluated by

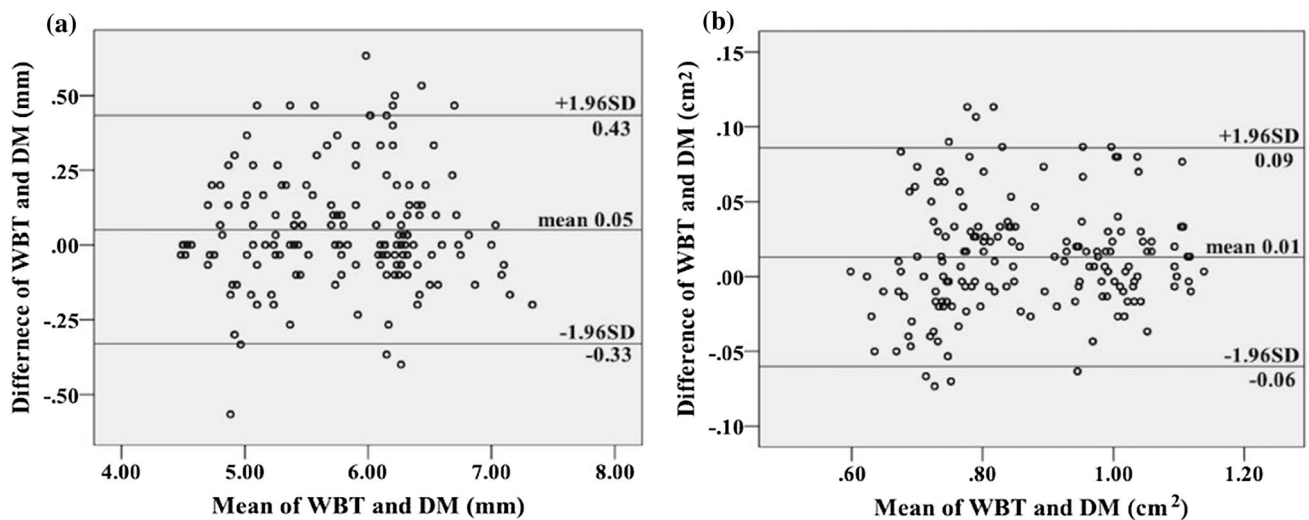


Fig. 4 Bland–Altman plots of the agreement between the water bath technique (WBT) and direct contact method (DM) for the mean thickness (a) and cross-sectional area (CSA) (b) of abductor pollicis brevis. Plots show the difference between the WBT and DM (y-axis)

relative to the mean of both measurements (x-axis). There was a total of 160 points in each analysis (80 hands \times 2 observers). $1.96 \times$ standard deviation (SD) of the difference between the WBT and DM was calculated as 95% limit of agreement

ultrasound. On the contrary, the probe in the WBT does not contact the skin, preserving the proper morphometry of the muscles. Indeed, Krishnamurthy et al. [10] reported that the WBT resulted in improved characterization of tissues in their native state, particularly when evaluating tissues in the extremities of children. Yet, the DM is most commonly used in the clinical setting to observe underlying structures. Given its widespread clinical use, it is important to clarify whether this technique provides the same structural information of the underlying structures or whether the contact made between the probe and the skin through the gel distorts the structures of interest. Indeed, specific to the APB, previous reports have recommended placing the probe lightly on the skin [6] or with sufficient transmission gel to avoid muscle compression [7]. Although these studies were concerned with the effects of probe contact on morphometry, they did not clarify whether the DM could reproduce the measurements that would be obtained with a non-contact method, such as the WBT. In our comparative analysis, we ensured complete separation of the probe and skin via transmission gel. As a result, we found that the DM could offer a comparable set of measurements as that obtained with the WBT if performed carefully. Our method is somewhat different to the so-called ‘direct method’ (i.e., applying pressure), but we believe that it can be regarded as a DM from the viewpoint of observing objects via transmission gel.

The reliability of the measurements depends on the examiner’s technique [7, 20]. König et al. [21] noted the reliability was more affected by probe positioning error than error arising from interpretation. Therefore, we defined a clear bony landmark for measurements. This positioning may have

contributed to the almost-perfect reliability. It may also have contributed to the lack of difference in the measured distances between the probe and the skin surface between the two techniques.

This study has several limitations. First, the sample size could not be verified by power analysis. However, the number of samples was almost the same as that in previous reports ($n = 62\text{--}77$) [6, 7]. Second, the examiner carried out all evaluations for both methods (WBT and DM) sequentially. Therefore, we could not avoid recall bias. Third, the sonographic technique was performed by examiners who had a comprehensive understanding of hand anatomy. This limitation may have reduced the differences in the measurements between the two methods. Fourth, the enrolled subjects were all relatively young and healthy volunteers. Because the APB thickness or CSA of older patients or patients with CTS is smaller than that of our subjects [7, 8], this will likely affect the probe pressure and, possibly, affect the measurement error. Further study is needed to evaluate the morphometry of the APB by both methods in healthy older people and those with CTS who typically have smaller APB muscles. Fifth, we did not consider how the difference in the acoustic coupling medium would affect the measurements. The acoustic coupling medium facilitates the propagation of acoustic energy between the probe and the object. When ultrasonography is performed in water, there is no gap between the probe and the specimen, so that acoustic energy tends to propagate. Yet, Casarotto et al. previously reported that there was little difference in the acoustic characteristics between gel and water [22]. On the other hand, Balmaseda et al. reported that gel offered a smaller degree of acoustic

attenuation and a better impedance match compared with water in their experimental set-up [23]. Due to the differences in experimental conditions, a consensus has not been reached. Furthermore, in phantom artery experiments using the WBT, Potter et al. measured the arterial lumen by separating the probe distance from 10 to 25 mm at an interval of 5 mm. As a result, they reported that a 5-mm increase in the distance between the probe and the artery reduced the measured lumen diameter by 0.04 mm [24]. In our study, the probe distance to the skin surface was less than 5 mm in WBT, with no statistically significant difference in the distance of the probe from the skin between the two methods. Hence, we regarded there to be little influence of the acoustic coupling medium in the evaluation of the two modes of ultrasound. Finally, we did not evaluate whether pressure changes, gravity, or the weight of the gel had an effect on the skin surface in DM or the effect of water pressure in WBT. However, our study showed that the measurements taken with the DM were not significantly different from those taken with the WBT, presumably suggesting little influence of these other outside factors.

The strength of this study was that the measurements of the APB obtained with the DM were comparable with those obtained with the WBT. We believe that it is important to pay particular attention to the position of the probe by maintaining sufficient gel between the probe and the object, and avoiding making contact between the probe and the skin. Even if sufficient transmission gel is used, there is a possibility that the probe will contact the skin, and this may cause deformation to the underlying connective tissues, fascia, and muscles. To avoid this, we ensured complete separation of the probe and the skin via transmission gel. In addition, the image is obtained while ensuring a space between the upper edge of the image and the skin surface. Although this method may not necessarily be the gold standard, we believe it is meaningful to show that the DM can reproduce the measurements that would be obtained with the WBT.

Conclusion

In conclusion, we showed that, similar to the WBT, the DM could be used to obtain measurements of APB thickness and CSA without causing morphometric changes through deformation to the shape of the muscle. This is important, as methods that can reliably identify muscles without affecting their morphology can be used to assess disease-related muscle changes, such as APB atrophy or weakness in patients with CTS. Further studies in CTS patients should be conducted to evaluate the severity or motor dysfunction that occurs due to APB atrophy in patients with CTS using the DM.

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Compliance with ethical standards

Conflicts of interest The authors have no conflicts of interest with regard to the presented research.

Ethical approval All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1964 and later versions.

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