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Recurrent motor branch neuropathy in carpal tunnel syndrome: An ultrasound study

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Abstract

Introduction/Aims: The reason for the variable rate of progression of patients with carpal tunnel syndrome (CTS) to thenar muscles impairment is not fully understood. The aim of this study was to evaluate the occurrence of ultrasound signs of recurrent motor branch (RMB) neuropathy in patients with CTS and to correlate imaging findings with clinical and electrophysiological data.

Methods: Two cohorts were recruited, one consisting of CTS patients with electrodiagnostic evidence of prolonged median distal motor latency from wrist to thenar eminence and another consisting of sex- and age-matched healthy controls. Ultrasound reliability of RMB measurement was assessed by the calculation of the interclass correlation coefficient (ICC). Patients were evaluated with electrodiagnostic tests and asked to complete the Boston Carpal Tunnel Questionnaire. The difference between the RMB diameter in patients and controls was analyzed using a *t* test. Correlations between RMB diameter and other parameters were assessed using linear mixed models.

Results: 46 hands from 32 patients with CTS and 50 hands from 50 controls were evaluated. The intra- and interobserver agreements in RMB measurement were very good (ICC = 0.84; 95% confidence interval [CI], 0.75 to 0.90) and good (ICC = 0.79; 95% CI, 0.69 to 0.87). The RMB diameter was significantly larger in patients than in controls ($P < .0001$). No significant correlation was found between the RMB diameter and other variables, except for BMI and median nerve cross-sectional area.

Discussion: Ultrasound is reliable in identifying the RMB and characterizing its abnormalities. In this patient cohort, ultrasound allowed for detection of definite signs of RMB compression neuropathy.

KEYWORDS
carpal tunnel syndrome, compression neuropathy, high-resolution ultrasound, nerve imaging, recurrent motor branch

Abbreviations: CTS, carpal tunnel syndrome; DML, distal motor latency; MN, median nerve; RMB, recurrent motor branch; SNCV, sensory conduction velocity; US, ultrasound.

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1 | INTRODUCTION

Sensory disturbances in carpal tunnel syndrome (CTS) are thought to precede motor impairment due to a relative increased susceptibility to ischemia of sensory axons, which demonstrate faster depolarization and early inactivation of Na^+ channels after prolonged compression.[1]

The recurrent motor branch (RMB) is a small but clinically relevant division of the median nerve (MN) that supplies the muscles of the thenar eminence (opponens pollicis, abductor pollicis brevis, and superficial belly of the flexor pollicis brevis), thus being responsible for most of the motor function of the thumb.[2–4] Although RMB neuropathy most commonly follows iatrogenic damage during surgical carpal tunnel release, compression injuries have been hypothesized to accelerate the progression of thenar muscles wasting in a subset of patients with CTS.[5–8] Anatomical variations of RMB origin and course have been sporadically suggested to expose the nerve to an increased risk of impingement; however, to date, the occurrence and the ultimate role of RMB neuropathy in patients with CTS have not been elucidated.[9,10]

High-resolution ultrasound (US) has shown potential to visualize the RMB, disclose the presence of anatomical variations, and characterize morphological changes in case of nerve pathology.[11–13] Accordingly, the aim of this study was to evaluate the occurrence of US signs of RMB neuropathy in a cohort of patients with CTS and electrodiagnostic evidence of prolonged median distal motor latency (DML) from wrist to thenar eminence and to correlate imaging findings with clinical and electrophysiological tests.

1.1 | Anatomical considerations

In most instances (extraligamentous or type I variant), after originating from the MN at the distal carpal tunnel, the RMB points to the palm (*first* or *vertical tract*), bends around the distal edge of the flexor retinaculum, and takes a retrograde course across the muscles of the thenar eminence (*second* or *horizontal tract*) (Figure S1). Anomalous paths are encountered in around 11% of people: the RMB may arise proximally within the carpal tunnel and then run underneath the flexor retinaculum alongside the MN (i.e., subligamentous path or type II variant), or may exit the carpal tunnel piercing the thickness of the retinaculum (i.e., transligamentous or type III variant).[14] In addition, the RMB may arise from the MN as single or multiple branches, may be variably oriented after branching from the MN, or may be overlayed by anomalous structures.[15,16] Finally, there is poor agreement about the mean transverse diameter of the RMB, with reported values ranging between 0.7 and 3 mm.[11,12]

2 | METHODS

Approval for this multicenter study, performed at the IRCCS Ospedale Policlinico San Martino (Genoa, Italy) and the Ospedale San Andrea (La Spezia, Italy), was obtained from the responsible ethics committee (Comitato Etico Regione Liguria, Protocol Code 12637, approved on October 7, 2022). After supplying informed consent, two cohorts were enrolled, respectively consisting of patients from the Neurophysiology Unit of the Ospedale San Andrea with electrophysiological evidence of CTS and prolonged DML and sex- and age-matched controls from the Radiology Unit of the IRCCS Ospedale San Martino without clinical evidence or history of CTS. Exclusion criteria for the two cohorts consisted of: (i) diagnosis of polyneuropathy and (ii) previous surgical procedures or major trauma near the wrist.

2.1 | Clinical and electrophysiological evaluation of patients

All patients were requested to complete the Boston Carpal Tunnel Questionnaire (BCTQ), which has been demonstrated to represent a valid primary outcome measure in CTS trials.[17] The BCTQ evaluates two domains of CTS: "symptoms" (SYMPT = patient-oriented symptoms) assessed on an 11-item scale; and "functional status" (FUNCT = patient-oriented function) assessed on an 8-item scale. Each item includes five possible responses, and the score for each domain is calculated as the mean of the responses of the individual items. In addition, the motor function of patients was evaluated and scored through the Medical Research Council (MRC) scale.[18]

Neurophysiological studies were performed on the same day as the US examination, according to accepted clinical standards.[19] The skin temperature was maintained at ≥32°C throughout the study and nerve conduction was measured orthodromically with superficial stimulation and recording. First-line tests included: (i) MN sensory conduction velocity (SNCV) from first digit to wrist (1 M); (ii) MN SNCV from third digit to wrist (3M); (iii) MN DML from wrist to thenar eminence; and (iv) radial nerve SNCV from first digit to wrist (1R). As recommended by the American Association of Electrodiagnostic Medicine,[20] when first-line tests yielded normal results, more sensitive studies (distal-to-proximal ratio) were carried out as follows: (i) MN SNCV from third digit to palm (3P); (ii) MN SNCV from palm to wrist (P-W), calculated as 3M−3P; (iii) the distal-to-proximal ratio (R), calculated as 3P / (P−W). Sensory and motor nerve conduction studies of the ulnar nerve were also carried out to exclude polyneuropathy. Patients were divided into six groups (i.e., negative tests or extreme, severe, moderate, mild, and minimal CTS) according to the accepted neurophysiological classification of CTS severity.[21] Patients with at least moderate CTS (DML ≥4 milliseconds or undetectable motor responses) were included in the study and underwent US evaluation.

2.2 | US examination and scanning technique in healthy volunteers

In volunteers, the RMB diameter was measured by two radiologists (F.Z. and R.P.) with, respectively, 7 and 5 years of experience in musculoskeletal US using a linear, high-frequency matrix array 18–5-MHz transducer and an ultra–high-frequency, 8-mm footprint, 22–8-MHz hockey-stick probe (Aplio i800 platform; Canon Medical Systems, Ōtawara, Japan). All volunteers were examined twice by one examiner, with 7 days elapsing between the two measurements, and once by the second examiner, who was unaware of the other observer's results. The RMB was first recognized as a thin fascicular structure running over the palmar surface of the flexor pollicis brevis and then was tracked distally until it was seen rejoining with the MN (Figure 1). In doubtful cases or when it was not possible to identify the RMB along its usual path, detection was attempted following the MN from proximal to distal along the carpal tunnel and trying to identify the RMB at its origin. The RMB diameter was measured shortly after branching from the MN at the level of the vertical tract. Transducer rotation on the RMB long axis, heel-toeing, and tilting were used to optimize the visualization of the nerve and reduce artifacts related to anisotropy.

2.3 | US examination in patients

All patients were evaluated by a single operator and the RMB diameter was measured at the level of the vertical tract as described in the previous section. In addition, the following parameters were collected: (i) MN cross-sectional area at the level of the proximal carpal row; (ii) MN cross-sectional area at the distal carpal row; and (iii) thickness of the flexor retinaculum. Flexor tendon tenosynovitis along the carpal tunnel and thenar muscle atrophy were subjectively graded in four classes (i.e., absent, mild, intermediate, or severe). Thenar muscle trophism was evaluated based on muscle echogenicity and volume, using as a reference the trophism of the flexor digitorum superficialis at the midforearm. Finally, predominant MN compression was defined as occurring at the proximal or distal part of the carpal tunnel considering the area of maximal nerve enlargement along its course across the tunnel itself.

2.4 | Statistical analysis

Descriptive values for continuous variables are reported as mean and standard deviation and categorical variables are reported as frequency (percent). After verification of normality, a comparison of demographic and clinical characteristics between study groups was assessed using *t* tests for independent groups or chi-square tests, as appropriate. The intra- and interobserver reliabilities in US measurement of the RMB diameter were established by calculating the intraclass correlation coefficient (ICC) and its 95% confidence interval (CI) using an absolute agreement, two-way random-effects model. ICC reliability was interpreted as poor (<0.20), fair (0.21 to 0.40), moderate (0.41 to 0.60), good (0.61 to 0.80), or very good (0.81 to 1). In patients, associations between the RMB diameter and other clinical, electrophysiological and US data were assessed using a linear mixed model with the RMB diameter as a dependent variable and unstructured covariance matrix. All data-processing steps and statistical analyses were performed in SAS version 9.4 (SAS Institute, Cary, NC, USA).

3 | RESULTS

3.1 | Study populations

The demographic characteristics of the investigated cohorts are shown in Table 1. According to electrophysiology, CTS was classified

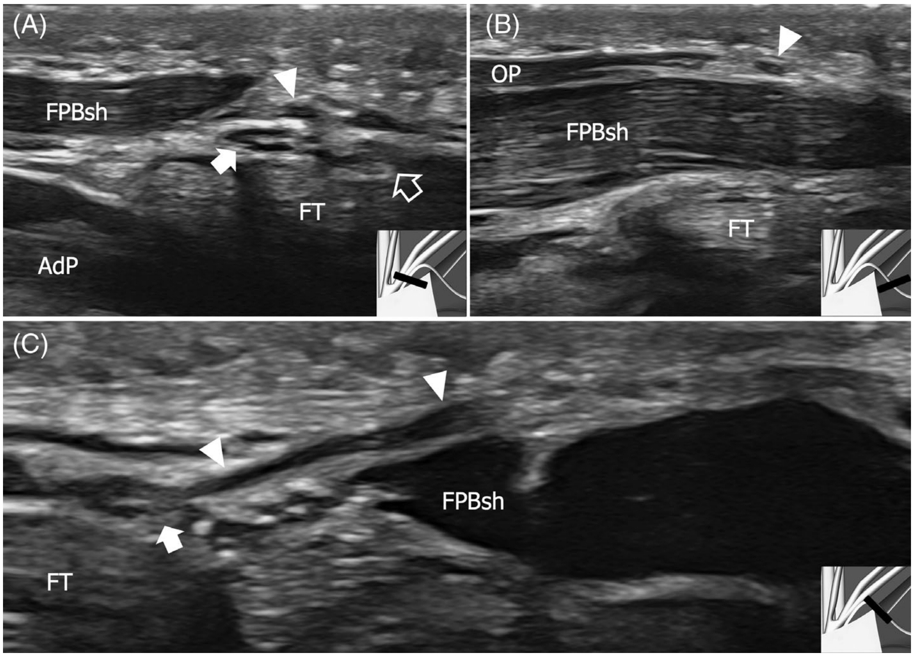

FIGURE 1 Recurrent motor branch normal anatomy. (A) Distal and (B) proximal short-axis 22–8-MHz US images and (C) long-axis 22-8 MHz US image obtained at the level of the thenar eminence demonstrate the course of the recurrent motor branch of the median nerve (arrowhead). In (A), the nerve is shown at the vertical tract shortly after its origin from the radial division of the median nerve (arrow). In (B), the recurrent motor branch is demonstrated at the horizontal tract, over the ventral surface of the superficial head of the flexor pollicis brevis muscle (FPBsh). Outlined arrow indicates ulnar division of the median nerve. AdP, adductor pollicis; FT, flexor tendons; OP, opponens pollicis. The panel at the bottom right corner of each image indicates the position of the probe.

TABLE 1 Demographics of the investigated cohort and recurrent motor branch diameter

	Patients	Volunteers	*P* value
Number	46 / 32[a]	50	
Gender, n (%)			.707
Female	19 (59.38%)	28 (56.00%)	
Male	13 (40.63%)	22 (44.00%)	
Age (years), mean (SD)	62.31 (12.63)	61.36 (12.55)	.826
BMI, mean (SD)	24.99 (4.68)	24.22 (2.93)	.713
Hands, n (%)			.763
Right	26 (56.42%)	30 (60.00%)	
Left	20 (43.48%)	20 (40.00%)	
Right-handed, n (%)	29 (90.63%)	45 (90.00%)	.926
Duration of symptoms (months), mean (SD)	24.03 (32.21)		
RMB diameter, mm	0.97 (0.30)	0.69 (0.14)	<.0001[b]

Abbreviations: BMI, body mass index; RMB, recurrent motor branch.

[a] Number of observations / number of patients.

[b] *P* value derived from a mixed model, which was applied to consider interhand correlation.

TABLE 2 Ultrasound, clinical, and electrophysiological results in the patient cohort

	Mean	SD
BCTQ function	2.31	0.83
BCTQ symptoms	2.86	0.72
SNCV	32.44	12.61
DML	5.51	2.25
Proximal MN CSA	13.70	5.00
Distal MN CSA	12.18	4.71
Thickness of retinaculum	0.87	0.22
Tenosynovitis n(%)		
Absent 29 (63%)		
Mild 16 (34.8%)		
Moderate 1 (2.2%)		
Severe 0 (0%)		
Thenar muscles atrophy n(%)		
Normal 37 (80.4%)		
Mild 5 (10.9%)		
Moderate 4 (8.7%)		
Severe 0 (0%)		
Neurophysiological severity n(%)		
Moderate 38 (82.7%)		
Severe 5 (10.8%)		
Extreme 3 (6.5%)		

Abbreviations: BCTQ Boston Carpal Tunnel Questionnaire; DML, distal motor latency; MN CSA; median nerve cross-sectional area; SD, standard deviation; SNVC, sensory nerve conduction velocity.

TABLE 3 Ultrasound, clinical, and electrophysiological variables associated with recurrent motor branch diameter

	β coefficient (95% CI)	*P* value
BMI	0.02 (0.004 to 0.04)	.021[a]
BCTQ function score	0.03 (−0.09 to 0.14)	.627
BCTQ symptoms score	0.005 (−0.12 to 0.13)	.941
MRC scale	−0.04 (−0.24 to 0.16)	.672
Duration of symptoms	0.001 (−0.002 to 0.003)	.608
Neurophysiological severity	0.09 (−0.05 to 0.24)	.197
SNCV	−0.003 (−0.01 to 0.004)	.431
DML	0.01 (−0.04 to 0.07)	.675
Proximal MN CSA	0.02 (0.005 to 0.04)	.015[a]
Distal MN CSA	0.02 (0.0005 to 0.04)	.044[a]
Thickness of flexor retinaculum	0.09 (−0.32 to 0.50)	.673
Thenar muscles atrophy	0.01 (−0.14 to 0.16)	.876
Tenosynovitis	−0.01 (−0.18 to 0.16)	.890

Abbreviations: BMI, body mass index; BCTQ FUNCT, Boston Carpal Tunnel Questionnaire; CI, confidence interval; DML, distal motor latency; MN CSA, median nerve cross-sectional area; MRC, Medical Research Council; SNVC, sensory nerve conduction velocity.

[a] Statistically significant (*P* < .05).

as moderate, severe, and extreme in 38, 5, and 3 hands, respectively. In 71.7% of the patients, the clinical exam demonstrated normal thenar muscle strength (MRC score = 5), whereas 28.3% of the patients were graded MRC score = 4. This cohort was matched for sex, age, and BMI with healthy controls (Table 1).

3.2 | US, clinical, and electrophysiological evaluation

Tables 2 and 3 show US, clinical, and electrodiagnostic results, respectively, obtained in the patient cohort and their correlations with RMB diameter. US allowed the identification of the RMB in all of the patients and volunteers. In both cohorts, the nerve was consistently found running on the palmar surface of the distal part of the flexor pollicis brevis and, from this point, was tracked back until its origin from the MN. In 4 of 96 hands (4.1%), the RMB was seen to detach from the MN inside the carpal tunnel and then run parallel to it until the distal edge of the retinaculum. Overall, it was not possible to

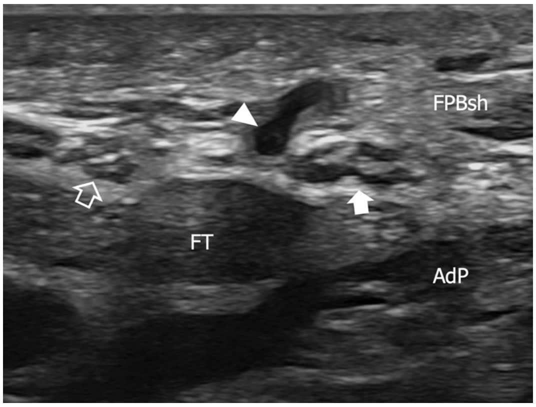

FIGURE 2 Recurrent motor branch compression neuropathy in a 68-year-old male patient with carpal tunnel syndrome. Transverse 22–8-MHz US image demonstrates an enlarged recurrent motor branch (arrowhead) arising from the radial division of the median nerve (arrow). Note the increased echogenicity of the superficial head of the flexor pollicis brevis (FPBsh) compared with the normal echogenic adductor pollicis (AdP), in relation to moderate atrophic changes affecting the first. Outlined arrow indicates ulnar division of the median nerve. FT, flexor tendons.

reliably establish if at this level the RMB pierced the most distal part of the retinaculum or bent around the distal edge to reach the thenar musculature.

The intra- and interobserver agreements in RMB measurement were very good (ICC = 0.84; 95% CI, 0.75 to 0.90) and good (ICC = 0.79; 95% CI, 0.69 to 0.87), respectively, confirming the reliability of US in the evaluation of this small nerve. The mean RMB diameter at the level of the vertical tract in patients was significantly larger than the RMB diameter in volunteers (0.97 vs. 0.69, *P* < .0001) (Figure 2). In patients, the RMB diameter was significantly associated with BMI, distal MN cross-sectional area, and proximal MN cross-sectional area. In 17 of 46 (36.96%), the MN was maximally enlarged at the level of the distal carpal tunnel, due to predominant compression against the distal edge of the flexor retinaculum. However, the RMB diameter was not significantly different between patients with proximal (mean = 0.95 mm, SD = 0.31 mm) and distal (mean = 1.00 mm, SD = 0.29 mm) MN compression (*P* = .960, derived from a mixed model, which was applied to consider interhand correlation) (Figure 3).

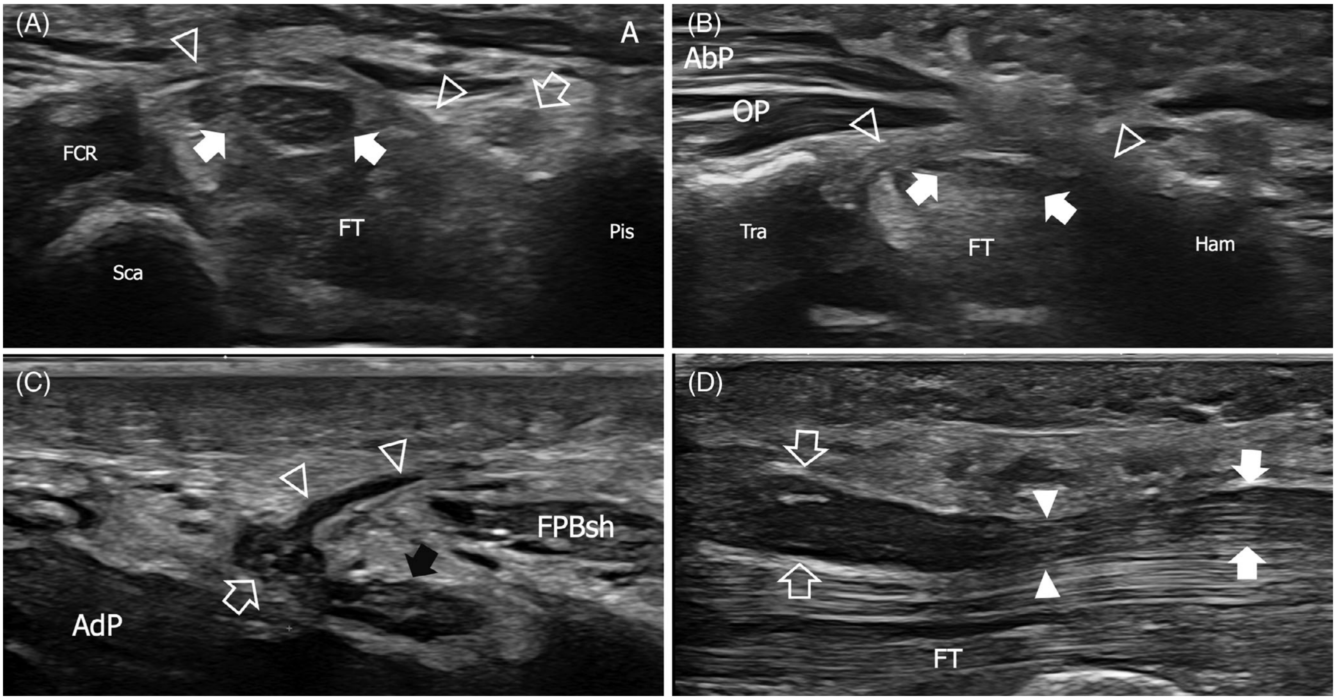

FIGURE 3 Recurrent motor branch neuropathy in a 74-year-old patient with distal median nerve compression. (A) Short-axis 18–5-MHz US image obtained at the level of the scaphoid (Sca) and pisiform (Pis) bones demonstrates an enlarged median nerve (white arrows) running between the flexor retinaculum (outlined arrowheads) and the flexor tendons (FT). (B) Short-axis 18–5-MHz US image shows the abrupt flattening of the median nerve (white arrows) as it passes underneath the thickened distal part of the flexor retinaculum (arrowheads). Note the origin of the abductor pollicis brevis (AbP) and the opponens pollicis (OP) from the retinaculum and the trapezium (Tra). Pis, pisiform. (C) Short-axis 18–5-MHz US image demonstrates edematous changes affecting the recurrent motor branch. Note the markedly swollen ulnar (outlined arrow) and radial (black arrow) divisions of the median nerve and the anomalous origin of the recurrent motor branch from the first. AdP, adductor pollicis; FPBsh, superficial head of the flexor pollicis brevis. (D) Long-axis 18–5-MHz US image shows the inverted notch sign (arrowheads), with significant swelling and hypoechogenicity of the median nerve at the distal carpal tunnel (outlined arrows) and almost normal nerve appearance at the proximal tunnel (arrows), in relation to predominantly distal nerve compression. Ft, flexor tendons.

4 | DISCUSSION

In this study, high-resolution US has been demonstrated to be accurate and reproducible in measuring the RMB diameter at the level of the vertical tract, with intra- and interobserver agreements rated very good and good, respectively. In our cohort, the RMB diameter averaged 0.69 mm (SD = 0.14 mm), in agreement with the results presented in a recently published US study.[12] In addition, a statistically significant enlargement of the RMB was demonstrated in patients affected by CTS and altered DML.

In compression neuropathies, US demonstration of nerve swelling is related to the impaired venous drainage and the progressive accumulation of intraneural fluids caused by the increased pressure on the vasa nervorum. US allowed the detection of signs of RMB edema in patients with CTS and altered DML, thus showing the potential to provide evidence of motor axons damage in this cohort. Notably, in our series of patients, the RMB diameter was not correlated with any clinical or neurophysiological parameter, whereas a significant positive correlation was found with BMI and MN cross-sectional area–the latter measured both at the proximal and distal edge of the flexor retinaculum.

On the other hand, the absence of correlations between the RMB diameter, CTS symptoms, and neurophysiological class may have different explanations. First, nerve enlargement may not be proportional to the severity of compression, as peripheral nerve may shrink in very advanced syndromes due to the occurrence of intraneural fibrotic changes.[22] Then, according to Padua's classification, an upgrade from grade 3 to grade 4 is only driven by a worsening of sensory function and does not require worsening of motor function. In addition, DML does not show a linear increase in advanced grades of CTS severity, as it tends to increase from mild to severe cases; however, it cannot be calculated in extreme CTS, which is characterized by an absent motor response.

The positive correlation between the RMB diameter and MN CSA demonstrates that the edematous changes found in this distal division are more prominent when the main nerve trunk is more severely swollen at the level of the carpal tunnel. This may be explained by considering that axonal edema in compression neuropathies is maximal around the compression point but tends to persist a few centimeters proximal or distal to it, and the motor axons compressed inside the carpal tunnel may show signs of nerve edema after having branched from the main nerve trunk. However, we did not find any difference in the RMB diameter between patients with prevalent proximal or distal compression, suggesting that there is no additional risk of RMB edema when the MN is more prominently compressed around the origin of the RMB itself. In addition, the thickness of the flexor retinaculum and the presence of flexor tendons tenosynovitis were not significantly linked to the degree of RMB swelling. Overall, we were not able to demonstrate a single anatomic factor associated with more prominent RMB edema other than the degree of MN swelling. However, we cannot exclude that minor anatomical variations not detected by US, such as anomalous carpal tunnel shapes or abnormal and inhomogeneous thickening of the flexor retinaculum, may cause a redistribution of the pressure forces exerted against the MN and predispose motor fascicles to earlier and more pronounced damage in some patients. In addition, variation in the fascicular topography of the MN at the level of the carpal tunnel may contribute to explaining the multifaceted clinical course of CTS, with more severe motor impairment occurring when motor fascicles are in close contact with the retinaculum or in areas of the nerve more prone to compression and ischemia.[23] In the end, we cannot exclude the existence of a subgroup of patients with CTS predisposed to early prolongation of DML as a consequence of local anatomical factors.

Our study has several limitations. We were able to include only a small sample of patients with CTS. Larger and multicenter studies are needed to confirm our results. We also did not include any patients with mild CTS and normal motor conduction studies. Consequently, we cannot assume the existence of any difference between the RMB involvement in patients with or without alteration of DML detected on electrodiagnostic testing.

In conclusion, high-resolution US is reliable in identifying the RMB of the MN and characterizing its abnormalities. In patients with CTS and altered DML, US allowed the detection of definite signs of RMB compression neuropathy. Prospective studies are needed to investigate if the identification of RMB edema by means of high-resolution US indicates an additional risk of CTS progression and may play a role in leading to a recommendation that such patients undergo prompt carpal tunnel release.

AUTHOR CONTRIBUTIONS

Riccardo Picasso: Conceptualization; methodology; data curation; validation; writing – original draft; writing – review and editing. **Federico Zaottini:** Conceptualization; methodology; formal analysis; validation; writing – review and editing; investigation. **Federico Pistoia:** Conceptualization; validation; writing – review and editing. **Alessandro Beronio:** Conceptualization; methodology; investigation. **Francesca Bovis:** Formal analysis; data curation. **Mehrnaz Hamedani:** Validation; formal analysis. **Angelo Schenone:** Conceptualization; investigation. **Carlo Martinoli:** Supervision; conceptualization; writing – review and editing.

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None.

CONFLICT OF INTEREST STATEMENT

None of the authors has any conflict of interest to disclose.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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