

Comparison of median nerve area measurement between MRI and electromyography in patients diagnosed with carpal tunnel syndrome

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Abstract

Background. Carpal tunnel syndrome (CTS) is the most common entrapment neuropathy that occurs when the median nerve is compressed within the carpal tunnel. Electromyography (EMG) is accepted as the most frequently used and important diagnostic method for CTS. Recently, magnetic resonance imaging (MRI) has begun to be used in CTS patients to directly visualize the median nerve and examine the changes occurring in the nerve structure.

Objectives. In this study, the area of the median nerve was measured at various levels in the wrist in patients with CTS using MRI, examining its relationship with signal increase, and comparing this to results obtained with EMG.

Materials and methods. Overall, 35 patients diagnosed with CTS were included in the study. Patients with normal-mild and moderate-severe EMG tests were included in the study; wrist MRI was taken to investigate the area/mm² of the median nerve at various levels and whether there was an increase in signal. Thenar muscles included in the imaging were also evaluated.

Results. Of the 35 patients included in the study, 24 were women (68.6%) and 11 were men (31.4%). Measurements of the average median nerve area measured in mm² at the distal radioulnar junction (DRUJ) and the median nerve area measured in mm² at the hamate bone level were obtained, showing that DRUJ and hamate bone distance measurements were higher in patients with positive EMG. Electromyography findings were also significantly positive in patients with increased signal.

Conclusions. In some cases, the diagnosis of CTS can be easily made with history and physical examination or employing confirmatory tests such as EMG, which is considered the gold standard. Magnetic resonance imaging can be used as an alternative method for imaging the median nerve in patients with CTS. In our study, EMG findings were also significantly positive in patients with increased signal on MRI, making it a preferable method, especially in soft tissue-related pathological cases.

Key words: magnetic resonance imaging, median nerve, carpal tunnel syndrome, carpal tunnel measures

Cite as

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Background

Carpal tunnel syndrome (CTS) occurs as a result of compression of the median nerve in the carpal tunnel, resulting in entrapment neuropathy.¹ It often appears as idiopathic, but there are also some underlying causes, with many pathological conditions and some anatomical variations that can compress the nerve and cause CTS.² Symptoms of the disease range from numbness and paresthesia in mild cases of impingement to loss of dexterity and thenar muscle atrophy in moderate and severe cases. In 1956, Simpson demonstrated that median nerve distal motor conduction time was prolonged in patients with CTS.³ Thus, electromyography (EMG) began to be used in diagnosis.

Electromyography is accepted as the most frequently used and important diagnostic method.⁴ For the most part, electrodiagnostic tests performed with nerve conduction studies (NCS), especially when including needle EMG, have high sensitivity and specificity to confirm CTS and eliminate other diagnoses.^{4,5} Polyneuropathy, plexopathy and radiculopathy can also be considered in the differential diagnosis. Electromyography evaluates evidence of pathological changes in the muscles innervated by the median nerve. If a secondary axonal loss occurs, EMG can reveal either active denervation (e.g., spontaneous activity such as fibrillation potentials, positive sharp waves and fasciculation potentials) or chronic changes indicating denervation with subsequent reinnervation (e.g., changes in motor unit action potential amplitudes, durations and recruitment). These findings support the diagnosis of CTS in the context of normal findings both in muscles not innervated by the median nerve and in muscles innervated by the proximal median nerve.⁶

Electromyography and its components for the diagnosis of CTS

Electrodiagnostic evaluation of a patient with suspected CTS is performed to confirm the diagnosis, to exclude compression located more proximally to the median nerve (brachial plexus lesion, C6 or C7 radiculopathy) and to determine the severity of median nerve involvement. According to the symptoms and findings of clinically diagnosed patients, these tests are positive in approx. 95% of cases.⁷

The median nerve innervates 4 muscles in the hand, namely the abductor pollicis brevis, flexor pollicis brevis, opponens brevis in the thenar region, and the 1st and 2nd lumbrical muscles in the interosseous region. Two or more C6–C7 innervated muscles (pronator teres, triiceps brachii, extensordigitorum communis) are evaluated to look for evidence of cervical radiculopathy. If the abductor pollicis brevis is abnormal, additional muscles are typically evaluated.⁴ This includes median-innervated muscles proximal to the carpal tunnel (e.g., flexor carpi radialis, pronator teres, flexor pollicis longus) to exclude proximal median neuropathy. Non-median-innervated

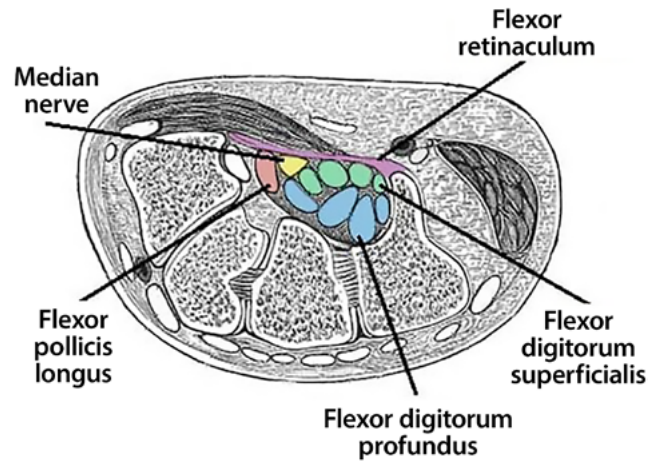


Fig. 1. Transverse section of the carpal tunnel

muscles are evaluated (e.g., the 1st dorsal interosseous and the extensor indicisproprius) to rule out brachial plexopathy, polyneuropathy and C8 to T1 radiculopathy.

In normal adults, median nerve distal motor conduction time varies between 2.0 μ s and 4.5 μ s and usually does not exceed 4.7 μ s.⁷ There may be a prolongation in CTS that exceeds this value. Meanwhile, in most cases, median nerve motor conduction velocity in the forearm is normal. Routine motor nerve conduction techniques are applied to the muscles innervated in the thenar region. In a patient with suspected CTS, the investigation begins with studies of the 1st finger sensory action potentials (SAP), 2nd finger SAP (median nerve) and 5th finger SAP (ulnar nerve), and it is monitored whether the signals received during EMG are different from normal. The lower limit of sensory nerve conduction in the hand is set at a conduction velocity of 42 m/s and amplitude of 10 μ V.

In recent years, the anatomical view of the carpal tunnel has been evaluated in detail with radiological imaging methods. Figure 1 shows the transverse section of the carpal tunnel anatomy. This has added a new dimension to CTS diagnosis and surgery. In magnetic resonance imaging (MRI), the median nerve in axial sections can be evaluated, which appears more rounded at the distal radioulnar junction (DRUJ) (Fig. 2A,B). The median nerve appears at the same intensity as skeletal muscles on T1-weighted images and minimally hyperintense on T2-weighted images.⁸ In patients with CTS, it was observed that the signal intensity of the median nerve increased at the level of the hamate bone (Fig. 3A).

Carpal tunnel syndrome most often occurs idiopathically, and can also be observed in pregnancy, diabetes, obesity, and hypothyroidism. The diagnosis of CTS is often made using history, clinical examination and electrodiagnostic tests. Recently, MRI has also been widely used in CTS to image the median nerve, evaluate nerve compression and detect additional pathologies.⁹

In our study, the area size/mm² of the median nerve at the hamate and DRUJ level, the signal increase

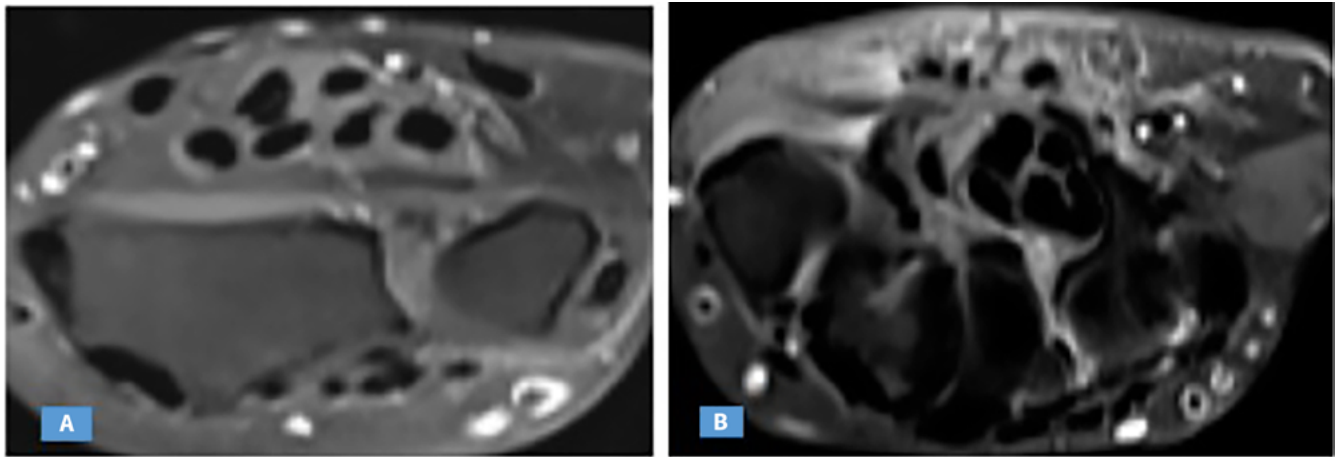


Fig. 2. A. Proton density-weighted fat-suppressed axial images show median nerve with a normal ovoid shape and signal intensity at the level of distal radioulnar joint; B. Elliptic shape at the level of the hamate bone

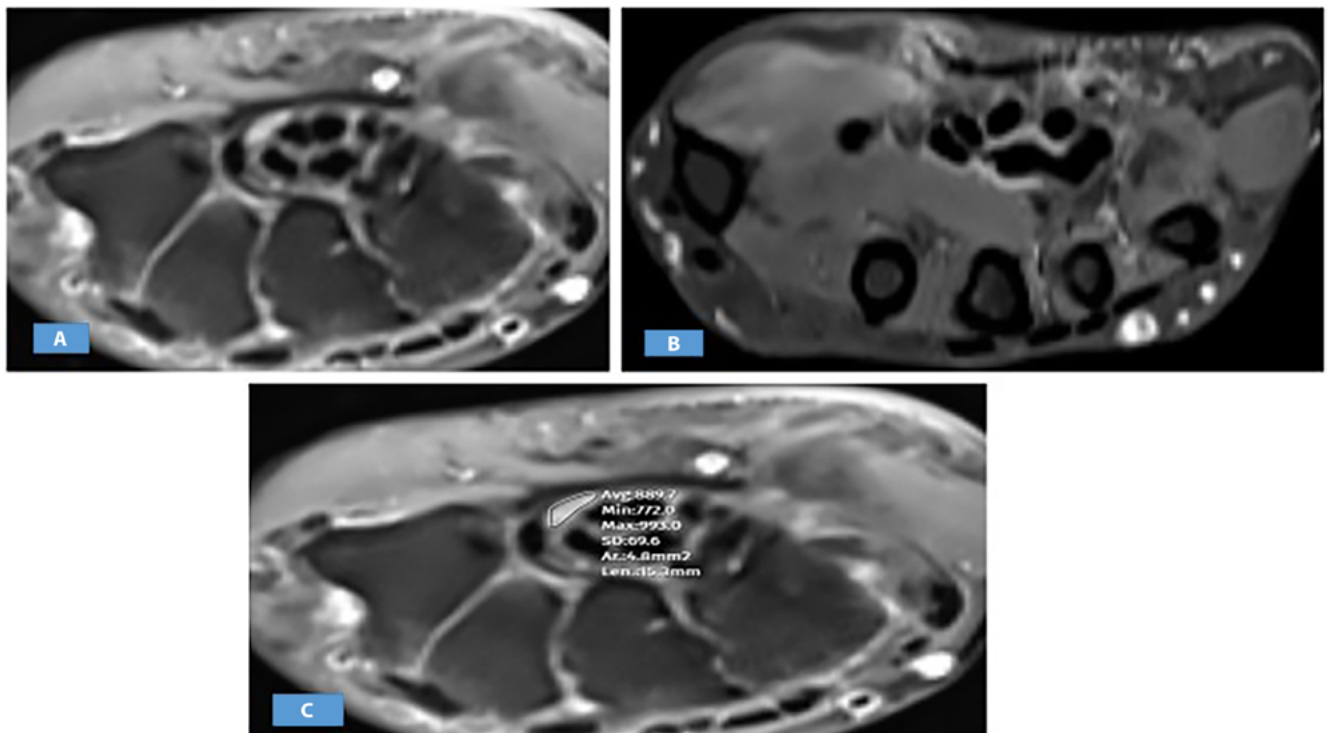


Fig. 3. A. Proton density-weighted fat-suppressed axial image shows the increased signal intensity of the median nerve at the level of the hamate bone in a patient with carpal tunnel syndrome (CTS); B. Proton density-weighted fat-suppressed axial image shows thenar muscle atrophy in a patient with CTS; C. Measurement of median nerve cross-sectional area with free region of interest (ROI) at the level of hamate bone on proton density-weighted fat-suppressed (PDW FS) axial image

of the nerve, and whether there was atrophy in the thenar muscles were investigated (Fig. 3B). Although they are more common in patients with CTS, these anatomical abnormalities seen on MRI are not specific. In its natural state, the median nerve is observed to be moderately flattened within the carpal tunnel. Studies have reported that the average flattening ratio at the level of the hook of the hamate bone is 2.9, and that the flattening ratio of a perfect circle is 1. In a study by Upadhyaya et al., the flattening ratio at the level of the distal radioulnar joint, pisiform and hamate was 1.7, 2.2, and 3.4, respectively. Patients with CTS usually demonstrate flattening ratio of more than 3 at this level.¹⁰

Carpal tunnel and median nerve anatomy

The carpal tunnel is a tunnel consisting of fibrous and osseous structures at the wrist and it is formed by 2 layers: a deep carpal arch and a superficial flexor retinaculum. The deep carpal arch forms a concave surface, which is converted into a tunnel by the overlying flexor retinaculum (transverse carpal ligament). The floor of the carpal tunnel is formed by the wrist bones, and the ceiling is formed by a thick ligament structure called the flexor retinaculum.¹¹ The flexor retinaculum is thickest distally and attaches to the hook of the hamate and

the tubercle of the trapezium. The median nerve divides into 2 branches at the exit of the carpal tunnel, the recurrent branch and the palmar digital nerves. The palmar digital nerves give sensory innervation to the palmar skin and dorsal nail beds of the lateral 3.5 digits. They also provide motor innervation to the lateral 2 lumbricals. The recurrent branch supplies the thenar muscle group.¹¹

Objectives

Electromyography is considered the most frequently used and important diagnostic method in the diagnosis of carpal tunnel syndrome. Recently, MRI has also started to be used for diagnostic purposes. This study aimed to demonstrate that MRI can be used to directly visualize median nerve morphological changes in CTS.

Hypothesis of the study

MRI can be used as an alternative diagnostic method. EMG findings and NCS results generally support the diagnosis of CTS, but specificity and sensitivity remain low in some cases. Magnetic resonance imaging allows to see the anatomical condition of the median nerve in detail before surgery, which is important for performing the surgery accordingly.

Materials and methods

A total of 35 patients with CTS symptoms who applied to Kayseri City Hospital Neurosurgery Clinic (Kayseri, Turkey) between July and October 2023 were included in the study. The EMG test was applied to all of them. Patients with normal EMG tests were also included in the study as a control group. Wrist MRIs were performed on all patients to monitor whether it was correlated with EMG. The study was approved by the Nuh Naci Yazgan University Ethics Committee (approval No. 2023/007-004 dated 20/07/2023).

Study design

The study was conducted in accordance with the Declaration of Helsinki, with the informed consent of the patients. The first choice in the diagnosis of CTS was an EMG test performed in all patients by a neurophysiologist. An MRI was taken to examine the wrist in those patients diagnosed with CTS as a result of EMG evaluation. The signal increase in the carpal tunnel of the median nerve, the area of the nerve/mm² and whether there was atrophy in the thenar muscles were evaluated by a radiologist (at the distal radioulnar junction and hamate bone levels) (Fig. 3C).

Diagnostic algorithm for patients with suspected CST

Clinical findings included numbness and paresthesia, the appearance of symptoms in the distribution of the median nerve, reduction of symptoms by changing hand position, provocation of symptoms by sleep, pain in the hand or arm, whether symptoms were provoked by the repetitive or sustained movement of the hand or arm, reduction of symptoms with hand-shaking, loss of sensation in the median nerve distribution, thenar muscle atrophy or weakness, and positive Tinel's or Phalen's tests. These were followed by EMG recordings, the data of which were then forwarded to our research group.

Electrophysiological methods

The diagnosis of CTS was made based on the patient's clinical findings and EMG studies.¹ Median nerve compression level in patients was measured using an EMG device with Keypoint.Net Software License® and serial No. 38375 (Natus Medical, Skovlunde, Denmark).

Electromyography measures the sum and activity of action potentials from muscle fibers under electrodes placed on the skin. The more muscles fibre, the greater the amount of action potential recorded and the higher the EMG value.¹²

Median nerve motor and sensory conduction velocities (SCVs), compound muscle action potential amplitudes, distal motor latencies (DMLs), and sensory nerve action potential amplitudes were analyzed. Patients with normal-to-mild median nerve compression were compared with patients with a moderate-to-high degree of compression. In the presence of CTS symptoms, the diagnosis was considered confirmed if at least 1 absolute and 1 comparative electrophysiological parameter or 2 comparative electrophysiological parameters were abnormal. The clinical severity of CTS was assessed using a validated 3-stage scale based on the clinical and electrophysiological severity scales for CTS that follows: mild, moderate and severe CTS (Table 1).¹³

Electroneurophysiological classification in patients with pre-diagnosis of CTS

Mild CTS is defined as orthodromic, antidromic or palmar median distal sensory conduction prolongation and an additional decrease in the amplitude of the distal action potential below normal.

Moderate CTS is the prolongation of median distal sensory conduction in an orthodromic, antidromic or palmar way is defined as a decrease in distal action potential amplitude below normal in addition to prolongation of median nerve DML.

Severe CTS is usually defined as the absence of distal action potential, a severe decrease in thenar motor response amplitude and a delay in distal latencies. It is defined

as the appearance of partial denervation findings on the thenar EMG.

The data obtained as a result of the evaluations made by the neurophysiologist were later reported for comparison with the MRI results. The clinical symptoms of the patients were added to the recorded EMG and MRI findings and analyzed.

Magnetic resonance imaging protocol

Images of all patients were acquired on a 3T scanner (Magnetom-Essen; Siemens AG, Munich, Germany). Patients were scanned in a prone position with their arms above their heads (Superman position). The wrist was located at the center of the scanner. The MRI protocol was created from a combination of 2-dimensional (2D) and 3-dimensional (3D) sequences in multiple planes. T1-weighted (T1W) and T2-weighted (T2W) spectral adiabatic inversion recovery (SPAIR) sequences were imaged in the axial plane. T1-weighted and proton density (PD) or fat-saturated (FS) sequences were generated in the coronal plane. The 3D PD SPAIR SPACE sequence was created in the sagittal plane. In the MRI image taken with the hand in the resting position, the area of the median nerve was measured, and the signal intensity was evaluated.

Statistical analyses

The data were curated and analyzed using IBM SPSS v. 22.0 software (IBM Corp., Armonk, USA). Frequency, percentage, mean value, standard deviation ($\pm$ SD), and highest and lowest (min–max) values were used for descriptive statistics. For statistical analysis of categorical data, Fisher's exact test was applied for values below 5 in 4-well tables. Shapiro–Wilk test was used to check the suitability of the data for normal distribution. For

statistical analysis of quantitative data in independent groups, the Mann–Whitney U test was used for data that did not comply with normal distribution, and the Pearson's correlation coefficient was used to show the relationship between variables. A statistically significant difference was accepted as $p < 0.05$.

Results

Of the 35 patients included in the study, 24 were women (68.6%) and 11 were men (31.4%), with an average age of 48.11 ± 11.66 years (min–max = 20–69). While creating the qualitative values of EMG data, the “Severity of Carpal Tunnel Syndrome Scale” was defined for CTS and used as a basis in many studies (Table 1).¹³ The frequency of EMG results, increased MRI signal of the median nerve and atrophy in the thenar muscles according to patient's sex are presented in Table 2. Electromyography results did not differ between sexes, while signal measurements on MRI did not show a significant difference between men and women, and atrophy in the thenar muscles was seen in 56% of women and all men ($p = 0.015$).

The patient EMG results, including atrophy and median signal status in the thenar muscles, are shown in Table 3. Electromyography findings were normal in 64% of patients with atrophy ($p = 0.474$) and significantly positive in patients with increased signal.

The average median nerve area at the DRUJ level of the patients was 9.44 ± 3.27 mm² (min–max = 4.60–17.20 mm²), and the median nerve area at the hamate bone level was 8.78 ± 3.29 mm² (min–max = 4.00–19.20 mm²). According to the determined confidence level, area measurement of the median nerve at the DRUJ level ($p = 0.041$; Mann–Whitney U test) was significantly higher, and hamate ($p = 0.055$; Mann–Whitney U test) bone level was higher in EMG-positive patients.

Table 1. Clinical and electrophysiological severity scales for CTS

Electrophysiological severity of CTS	Severity of CTS sensory NCS motor NCS		APB needle EMG
Mild At least 3 of the following sensory and motor nerve conduction	1. 14-cm wrist stimulation, peak latency >3.7 ms 2. 14-cm wrist stimulation, peak latency: proximal 7 cm >distal 7 cm 3. Transcarpal 5 cm short-segmental latency: onset latency >1.3 ms, peak latency >1.5 ms 4. 14-cm 16–20 μ V amplitude 5. Conduction block greater than 50% in wrist palm stimulation if 14 cm stimulation amplitude ≥ 20 μ V	6. Distal latency >4.2 ms 7. CMAP amplitude 4. 1–4.5 mV	normal
Moderate Mild + at least 2 of the following	1. Wrist stimulation (14 cm) SNAP amplitude ≥ 6 –15 μ V 2. Conduction block greater than 50% in wrist palm stimulation if SNAP ≥ 10 μ V with 14 cm wrist stimulation	3. CMAP amplitude 2. 1–4 mV 4. 1–4 mV	4. Fibrillation ($\pm$) 5. Abnormal MUAP with intermediate interference pattern
Severe Moderate + 1 of the following	1. SNAP amplitude ≤ 5 μ V	2. CMAP amplitude ≤ 2 mV	3. Fibrillation (+) 4. Abnormal MUAP with discrete activity or single unit pattern

CTS – carpal tunnel syndrome; NCS – nerve conduction study; APB – abductor pollicis brevis; EMG – electromyography; CMAP – compound muscle action potential; SNAP – sensory nerve action potential; MUAP – motor unit action potential.

Table 2. Frequency of EMG results; increased magnetic resonance imaging (MRI) signal of the median nerve and atrophy in the thenar and hypotenar muscles according to the gender of the patients

Variables		All patients	Gender				p-value
			female		male		
		n	n	%	n	%	
EMG	normal	21	14	66.7	7	33.3	0.533
	moderate/severe	14	10	71.4	4	28.6	
Signal	normal	24	15	62.5	9	37.5	0.230
	increased	11	9	81.8	2	18.2	
Atrophy in thenar muscles	positive	25	14	56.0	11	44.0	0.015
	negative	10	10	100.0	0	0.0	

Percentage of rows used; Fisher's exact test. EMG – electromyography.

Table 3. Electromyography (EMG) results of the patients; atrophy in thenar and hypothenar muscles and median signal status

Variables		EMG				p-value
		normal		increased		
		n	%	n	%	
Signal	normal	18	75.0	6	25.0	0.011
	increased	3	27.3	8	72.7	
Atrophy in thenar muscles	positive	16	64.0	9	36.0	0.474
	negative	5	50.0	5	50.0	

Percentage of rows used; Fisher's exact test.

Table 4. The area of the median nerve at the hamate bone distance in patients with thenar-hypertrophic muscle atrophy; the relationship between the area measurements at the DRUJ distance and atrophy

Variables		Area of the median nerve [mm ²]					
		DRUJ			Hamate		
		mean ±SD	median	min–max	mean ±SD	median	min–max
EMG	normal	8.38 ±2.52	8.8	4.6–13.4	7.88 ±2.98	7.9	4–13.2
	moderate/severe	11.02 ±3.70	9.75	5.3–17.2	10.12 ±3.38	9.8	6.2–19.2
p/U		0.041/86.500			0.055/90.000		
Signal	normal	9.11 ±3.37	8.9	4.6–17.2	7.77 ±2.72	7.6	4.0–13.2
	increased	10.14 ±3.07	9.5	5.3–16.1	10.99 ±3.47	11.3	6.2–19.2
p/U		0.319/104.000			0.009/58.000		
Atrophy in thenar and hypothenar muscles	positive	8.91 ±3.10	8.8	4–16.1	8.01 ±2.59	7.9	4.3–13.2
	negative	10.75 ±3.48	9.5	5.9–17.2	10.71 ±4.15	11.3	4.0–19.2
p/U		0.100/80.000			0.48/71.000		

Mann–Whitney U test; EMG – electromyography; DRUJ – distal radioulnar junction; SD – standard deviation.

Based on the specified confidence level, area measurements of the median nerve at the DRUJ bone level were significantly higher in EMG-positive patients ($p = 0.041$; Mann–Whitney U test), but measurements at the hamate levels of EMG-positive patients were not statistically significant ($p = 0.055$; Mann–Whitney U test), although this value can be considered borderline significant.

In patients whose median nerve signal was increased on MRI, the area at the hamate bone level was found to be significantly higher ($p = 0.009$; Mann–Whitney U test), but no significant relationship was shown between the DRUJ

($p = 0.319$; Mann–Whitney U test) level measurements and the signal increase of the median nerve. While the area of the median nerve at the hamate bone level was found to be significantly lower ($p = 0.04$; Mann–Whitney U test) in patients with thenar muscle atrophy, no significant relationship was shown between area measurements at the DRUJ level and thenar muscle atrophy ($p = 0.100$; Mann–Whitney U test) (Table 4).

Finally, no correlation was found between the age of the patients and the area measurements of the median nerve at the hamate bone level and the area measurements

at the DRUJ level ($p > 0.05$) ($p > 0.05$ correlation coefficient 0.001 and 0.251, respectively). However, a positive correlation was detected between hamate and DRUJ levels ($p < 0.001$ correlation coefficient 0.639).

Discussion

Diagnosis of CTS is usually based on the patient's history, although clinical examination, electrophysiological tests or imaging methods support the diagnosis and guide the surgeon. Determining the level of compression of the median nerve in the carpal tunnel and the cause of CTS is also important for surgeons planning the operation, because failure to make an accurate and definitive diagnosis may result in failure of the surgical treatment. In this case, symptoms may not disappear or may reoccur. Recently, 2 different surgical techniques have been used, namely open surgery and endoscopic treatment. With surgery, symptoms are largely relieved, and the development of motor deficits can be prevented.¹⁴ Return to work time after endoscopic treatment, which is a minimally invasive technique, is shorter compared to conventional open surgery. However, it is also reported that minor complications occur more frequently after endoscopy.¹⁵

The most frequently used alternative type in the diagnosis of CTS is median nerve ultrasonography (USG). It is a low-cost procedure that is frequently used in clinical examination and is easily accessible. It allows visualization of the median nerve with a surface probe used over the carpal tunnel. It provides a subjective evaluation and the results depend on the physician performing the ultrasound.

In clinical practice, plain radiography is mostly used to check the bone morphology of wrist joints, but the role of plain radiography in the diagnosis of CTS is limited. Ultrasound and MRI are used more often to check soft tissue condition. Due to the inability to check the soft tissue condition, the role of plain radiography in the diagnosis of CTS is limited. Han et al. examined plain radiographs of patients with CTS compared to a control group, aiming to reveal radiographic predictive factors for the development of CTS by comparing the radiological parameters of simple wrist radiographs. Their results showed that excessive dorsiflexion or volar displacement of the lunate compared to the radial shaft is a risk factor for CTS development.¹⁶

Magnetic resonance imaging can be used as an alternative method to visualize the median nerve, and it also provides a detailed evaluation of the median nerve and surrounding anatomy. However, since it is an expensive procedure, it would be better to use it only in selected cases. In our study, signal intensity changes in the median nerve and atrophy in the thenar muscles can also be examined with MRI. Electrophysiological evaluation is the first choice in Turkey due to its practical value and low cost, and we found that EMG results did not differ between

genders. Notably, EMG findings were significantly positive in patients with increased signal on MRI in our study.

Goetz et al. measured and evaluated local deformations of the median nerve seen in MRI images of the carpal tunnel. Twelve patients with CTS and 12 matched normal controls underwent MRI scanning in 8 isometrically loaded hand positions. During hand movements, healthy study participants had a higher mean percentage of locally deformed nerve edges than CTS patients, despite having a more rounded median nerve shape.¹⁷

In this study, we found that area measurements at the DRUJ level were significantly higher, and hamate bone level measurements were higher in patients with median nerve compression detected on EMG. We observed that the area at the hamate bone level was significantly higher in patients with increased median nerve signal on MRI. This showed that the nerve trapped under the flexor retinaculum was thicker due to edema and was observed with increased signal on MRI. In 1972, Phalen studied 598 hands with CTS and 235 of them were treated with open surgery.¹⁸ The normal median nerve flattens to some extent as it passes beneath the transverse carpal ligament. Obvious compression of the nerve, characterized by excessive flattening and thinning and narrowing of the nerve, or by a transverse groove in the nerve at the level of the proximal edge of the ligament, was found in 145 wrists. Of these, 119 were classified as mild, 22 wrists as moderate and 4 wrists as severe. Overall, 215 hands were operated on, and 110 had thenar atrophy (to a greater or lesser degree).

Sasaki et al. examined all clinical and Nerve Conduction Study (NCS) data from 560 patients (1,120 hands; median age, 69.5 years; 264 male hands, 856 female hands) treated at the Department of Orthopedic Surgery at the Tokyo Medical and Dental University, Japan. Their large dataset revealed a strong negative correlation between SCVs and DMLs in their NCSs in patients with CTS.¹⁹

Magnetic resonance imaging sequences that display the median nerve in various ways (such as T2W SPAIR, T1W and T2W FS sequences) allow the signal intensity and size changes of the nerve to be monitored in more detail.^{20,21} Upadhyaya et al. patients who had previously received treatment and were diagnosed with CTS based on clinical findings. The authors evaluated the cause of nerve compression by evaluating the signal intensity, cross-sectional area and nerve flattening rate at certain levels. There were many female patients in this study, potentially complicating their results as women develop CTS more frequently than men, and the age of the patients ranged from 35 to 65.¹⁰ In our study, 24 (68.6%) of 35 patients were female and 11 (31.4%) were male. The average age of the patients was 48.11 ± 11.66 (min–max = 20–69) years.

In patients with CTS, it is observed that the most significant increase in nerve diameter due to edema in the median nerve occurs at the pisiform bone level.²²

In our study, we compared and analyzed the area measurements of the median nerve at the hamate bone and DRUJ levels. The average median nerve area at the DRUJ level was $9.44 \pm 3.27 \text{ mm}^2$ (min–max = $4.60\text{--}17.20 \text{ mm}^2$), and the median nerve area at the hamate bone level was $8.78 \pm 3.29 \text{ mm}^2$ (min–max = $4.00\text{--}19.20 \text{ mm}^2$). According to the determined confidence level, area measurements of the median nerve at the DRUJ ($p = 0.041$; Mann–Whitney U test) and hamate bone levels were higher in EMG-positive patients ($p = 0.055$; Mann–Whitney U test).

Nakamichi et al. measured the cross-sectional area of the median nerve at the proximal tunnel level in 414 hands of 275 patients and 408 normal individuals. They determined it to be $14.4 \pm 4.3 \text{ mm}^2$ in patients and $9.6 \pm 2.4 \text{ mm}^2$ in healthy individuals.²³ At the distal radial level, they reported it to be $4.9 \pm 1.0 \text{ mm}^2$ in CTS patients and $4.8 \pm 1.0 \text{ mm}^2$ in healthy controls. A statistically significant difference ($p < 0.0001$) was observed between the distal radial level and the proximal canal level in the nerve area measurements.

Monagle et al. showed that the cross-sectional area of the median nerve, which courses within the proximal carpal tunnel, is approx. 50% larger in patients with CTS than in normal individuals.²⁴ A study where researchers used high-resolution MRI showed that when the cadaveric median nerve was examined proximal of the carpal tunnel, it was shown that it had an elliptical shape and its area was 12.9 mm^2 (average diameter of 3.3 mm and 4.9 mm). Signal increase was also evident on T2W images.²⁵

It is not possible to identify a diagnostic test that will diagnose CTS with 100% accuracy.¹⁰ In this case, we need to take into account many parameters that can contribute to the diagnosis of CTS as much as possible. Nerve conduction studies, which are adequate according to the literature, should be considered a good candidate for this purpose with its high sensitivity and specificity. In some cases, CTS can be easily diagnosed employing history and physical examination, although confirmatory tests, such as EMG, may be required.²⁶ Electrodiagnostic studies, rather than other clinical methodologies, were determined to be the most sensitive and specific.²⁷ Currently, a detailed evaluation of the anatomy of the carpal tunnel with MRI has added a new dimension to CTS surgery. Notably, the increased signal on T2-A sections in the median nerve is compatible with edema or demyelination, excessive contrast is compatible with edema in the nerve, and absence of contrast is compatible with ischemia. In the event of fibrosis occurring in the nerve, a loss of signal is observed.²⁸

Limitations

This study contains several limitations. The study was conducted prospectively, but the data were obtained retrospectively from scanning magnetic resonance images. As a result of power analysis and literature studies,

the sample group of the study was determined to be 35 patients, 15 of whom were normal controls.^{17,28} Although the sample was small, it was comparable to similar studies. Conventional shape measurements (cross-sectional area) of the median nerve and locally deformed CTS patients within the tunnel with increased signal were compared between CTS patients and a matched control group. Patients with diabetes-related polyneuropathy were excluded from the study. This is a cross-sectional study and may not reflect the general population.

Conclusions

In many cases, the first choice for diagnosis may be EMG or MRI. If both are easily accessible, the first choice should be EMG, and NCS has diagnostic value as part of the routine management of CTS patients and should be performed before surgery on any patient with suspected CTS. In cases where diagnosis can not be established, both can be applied together. Magnetic resonance imaging may be preferred in soft tissue-related pathological cases. In some cases, the use of EMG or MRI alone may not be sufficient. In clinical practice, it can be seen that we operate with the same EMG findings and with the same surgical method, but the patients do not benefit sufficiently. Even if nerve conduction is impaired, anatomical disorders should be demonstrated with MRI to support the correctness of the surgical decision. This is how surgical failure incidence can be reduced in modern medicine.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

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References

1. Spagnolo F, Sestak I, Howell A, Forbes JF, Cuzick J. Anastrozole-induced carpal tunnel syndrome: Results from the International Breast Cancer Intervention Study II Prevention Trial. *J Clin Oncol*. 2016;34(2):139–143. doi:10.1200/JCO.2015.63.4972
2. Stevens JC, Beard CM, O'Fallon WM, Kurland LT. Conditions associated with carpal tunnel syndrome. *Mayo Clin Proc*. 1992;67(6):541–548. doi:10.1016/S0025-6196(12)60461-3
3. Simpson JA. Electrical signs in the diagnosis of carpal tunnel and related syndromes. *J Neurol Neurosurg Psychiatry*. 1956;19(4):275–280. doi:10.1136/jnnp.19.4.275

4. Jablecki CK, Andary MT, Floeter MK, et al. American Association of Electrodiagnostic Medicine; American Academy of Neurology; American Academy of Physical Medicine and Rehabilitation. Practice parameter: Electrodiagnostic studies in carpal tunnel syndrome: Report of the American Association of Electrodiagnostic Medicine, American Academy of Neurology, and the American Academy of Physical Medicine and Rehabilitation. *Neurology*. 2002;58(11):1589–1592. doi:10.1212/WNL.58.11.1589
5. American Association of Electrodiagnostic Medicine; American Academy of Neurology; American Academy of Physical Medicine and Rehabilitation. Practice parameter for electrodiagnostic studies in carpal tunnel syndrome: Summary statement. *Muscle Nerve*. 2002;25(6):918–922. doi:10.1002/mus.10185
6. Kothari MJ. Carpal tunnel syndrome: Clinical manifestations and diagnosis. Philadelphia, USA: Wolters Kluwer. 2023. <https://www.uptodate.com/contents/carpal-tunnel-syndrome-clinical-manifestations-and-diagnosis/print>. Accessed October 15, 2023.
7. Eroğlu S. Electrodiagnostic methods using for carpal tunnel syndrome and its diagnosis [in Turkish]. *Journal of Harran University Medical Faculty*. 2013;10(2):86. <https://dergipark.org.tr/en/download/article-file/838048>. Accessed October 15, 2023.
8. Kumari A, Singh S, Garg A, Prakash A, Sural S. Tingling hand: Magnetic resonance imaging of median nerve pathologies within the carpal tunnel. *Pol J Radiol*. 2019;84:484–490. doi:10.5114/pjr.2019.90354
9. Thawait SK, Chaudhry V, Thawait GK, et al. High-resolution MR neurography of diffuse peripheral nerve lesions. *AJNR Am J Neuroradiol*. 2011;32(8):1365–1372. doi:10.3174/ajnr.A2257
10. Upadhyaya V, Upadhyaya ND, Pandey SD. MRI of the median nerve in carpal tunnel syndrome. *J Peripher Nerve Surg*. 2020;4:15–21. <https://www.thieme.in/thieme-e-Journals/jpnspdf/Article-3.pdf>. Accessed October 15, 2023.
11. Mesgarzadeh M, Schneck CD, Bonakdarpour A, Mitra A, Conaway D. Carpal tunnel: MR imaging. Part II. Carpal tunnel syndrome. *Radiology*. 1989;171(3):749–754. doi:10.1148/radiology.171.3.2541464
12. Elamvazuthi I, Duy NHX, Ali Z, Su SW, Khan MKAA, Parasuraman S. Electromyography (EMG) based classification of neuromuscular disorders using multi-layer perceptron. *Proc Comp Sci*. 2015;76:223–228. doi:10.1016/j.procs.2015.12.346
13. Kang S, Kwon HK, Kim KH, Yun HS. Ultrasonography of median nerve and electrophysiologic severity in carpal tunnel syndrome. *Ann Rehabil Med*. 2012;36(1):72. doi:10.5535/arm.2012.36.1.72
14. Petrover D, Richette P. Treatment of carpal tunnel syndrome: From ultrasonography to ultrasound guided carpal tunnel release. *Joint Bone Spine*. 2018;85(5):545–552. doi:10.1016/j.jbspin.2017.11.003
15. Sayegh ET, Strauch RJ. Open versus endoscopic carpal tunnel release: A meta-analysis of randomized controlled trials. *Clin Orthop Relat Res*. 2015;473(3):1120–1132. doi:10.1007/s11999-014-3835-z
16. Han BS, Kim KH, Kim KJ. The radiographic risk factors predicting occurrence of idiopathic carpal tunnel syndrome in simple wrist X-ray. *J Clin Med*. 2022;11(14):4031. doi:10.3390/jcm11144031
17. Goetz JE, Kunze NM, Main EK, et al. MRI-apparent localized deformation of the median nerve within the carpal tunnel during functional hand loading. *Ann Biomed Eng*. 2013;41(10):2099–2108. doi:10.1007/s10439-013-0809-3
18. Phalen GS. The carpal-tunnel syndrome: Clinical evaluation of 598 hands. *Clin Orthop Relat Res*. 1972;83:29–40. doi:10.1097/00003086-197203000-00007
19. Sasaki T, Koyama T, Kuroiwa T, et al. Evaluation of the existing electrophysiological severity classifications in carpal tunnel syndrome. *J Clin Med*. 2022;11(6):1685. doi:10.3390/jcm11061685
20. Chalian M, Behzadi AH, Williams EH, Shores JT, Chhabra A. High-resolution magnetic resonance neurography in upper extremity neuropathy. *Neuroimaging Clin N Am*. 2014;24(1):109–125. doi:10.1016/j.nic.2013.03.025
21. Howe BM, Spinner RJ, Felmlee JP, Frick MA. MR imaging of the nerves of the upper extremity. *Magn Reson Imaging Clin N Am*. 2015;23(3):469–478. doi:10.1016/j.mric.2015.04.009
22. Beekman R, Visser LH. Sonography in the diagnosis of carpal tunnel syndrome: A critical review of the literature. *Muscle Nerve*. 2003;27(1):26–33. doi:10.1002/mus.10227
23. Nakamichi K, Tachibana S. Ultrasonographic measurement of median nerve cross-sectional area in idiopathic carpal tunnel syndrome: Diagnostic accuracy. *Muscle Nerve*. 2002;26(6):798–803. doi:10.1002/mus.10276
24. Monagle K, Dai G, Chu A, Burnham RS, Snyder RE. Quantitative MR imaging of carpal tunnel syndrome. *Am J Roentgenol*. 1999;172(6):1581–1586. doi:10.2214/ajr.172.6.10350293
25. Altınok MT, Ertem K, Fırat AK, Karakaş HM. Patent median artery in a case with carpal tunnel syndrome bifid median nerve [in Turkish]. *İnönü Üniversitesi Tıp Fakültesi Dergisi*. 2005;12(4):273–275. <https://dergipark.org.tr/tr/download/article-file/139603#158032>. Accessed October 15, 2023.
26. Sonoo M, Menkes DL, Bland JDP, Burke D. Nerve conduction studies and EMG in carpal tunnel syndrome: Do they add value? *Clin Neurophysiol Pract*. 2018;3:78–88. doi:10.1016/j.cnp.2018.02.005
27. Stoller DW, Stoller DW. The wrist and hand. In: *Magnetic Resonance Imaging in Orthopaedics and Sports Medicine*. 2nd ed. Philadelphia: Lippincott Williams & Wilkins; 1997:959–961. ISBN:978-1-85233-149-8.
28. Deniz FE, Öksüz E, Sarıkaya B, et al. Comparison of the diagnostic utility of electromyography, ultrasonography, computed tomography, and magnetic resonance imaging in idiopathic carpal tunnel syndrome determined by clinical findings. *Neurosurgery*. 2012;70(3):610–616. doi:10.1227/NEU.0b013e318233868f