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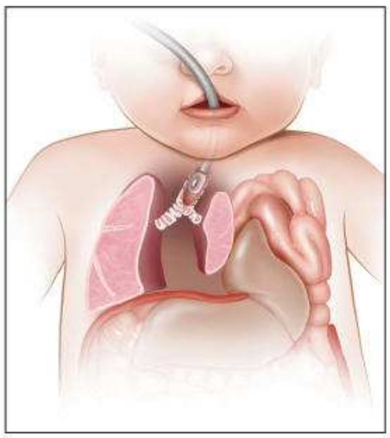

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High-Resolution Median Nerve Sonographic Measurements

Correlations With Median Nerve Conduction Studies in Healthy Adults

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Article includes CME test

Objectives—To study relationships between median wrist and forearm sonographic measurements and median nerve conduction studies.

Methods—The study population consisted of a prospective convenience sample of healthy adults. Interventions included high-resolution median nerve sonography and median motor and sensory nerve conduction studies. Main outcome measures included median motor nerve compound muscle action potential amplitude, distal latency, and conduction velocity; sensory nerve action potential amplitude and distal latency; and sonographic median nerve cross-sectional area. Median motor nerve and sensory nerve conduction studies of the index finger were performed using standard published techniques. A second examiner blinded to nerve conduction study results used a high-frequency linear array transducer to measure the cross-sectional area of the median nerve at the distal volar wrist crease (carpal tunnel inlet) and forearm (4 cm proximally), measured in the transverse plane on static sonograms. The outer margin of the median nerve was traced at the junction of the hypoechoic fascicles and adjacent outer connective tissue layer.

Results—Fifty median nerves were evaluated in 25 participants. The compound muscle action potential amplitude with wrist stimulation was positively related to the cross-sectional area, with the area increasing by 0.195 mm^2 for every millivolt increase in amplitude in the dominant hand (95% confidence interval, 0.020, 0.370 mm^2; $P < .05$) and 0.247 mm^2 in the nondominant hand (95% confidence interval, 0.035, 0.459 mm^2; $P < .05$). There was no significant linear association between the wrist median cross-sectional area and median motor and sensory distal latencies. Conduction velocity through the forearm was not significantly linearly associated with the forearm area or forearm-to-wrist area ratio (tapering ratio). The wrist area was inversely related to the sensory nerve action potential amplitude.

Conclusions—Although associations were found between median nerve conduction study amplitudes and sonographic nerve measurements, they were not found for other parameters. Studying these relationships may increase our understanding of when to best use these procedures.

Key Words—electrodiagnosis; nerve conduction; sonography

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Abbreviations

BMI, body mass index; CI, confidence interval; MRI, magnetic resonance imaging

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Median neuropathy at the wrist, or carpal tunnel syndrome, is the most common form of peripheral nerve entrapment and a considerable source of disability.[1] Clinical diagnosis is most often based on the history of symptoms, provocative influences, mitigating factors, and physical examination findings. In a recent prospective evaluation of 34 variables thought to be associated with carpal tunnel syndrome, sex, nocturnal symptoms, thenar atrophy, abductor pollicis brevis weakness, median sensory symptoms, and pinprick sensory examinations were more predictive of abnormalities on confirmatory electrodiagnostic testing.[2]

Nerve conduction studies have been used to confirm the clinical diagnosis of carpal tunnel syndrome and to identify concurrent or other disorders mimicking symptoms of median neuropathy, such as cervical radiculopathy and peripheral polyneuropathy.[3,4] Nerve conduction studies have been reported to be highly specific in some studies, particularly with the use of summary scores of multiple nerve comparisons across the wrist; however, even with such techniques, false-negative rates approach 15% and may be even greater when evaluations are only performed at longer distances across the wrist.[5] False-positive rates of 15% to 18% may be seen within specific populations.[6] Nerve conduction studies can help indicate the level of abnormality but do not give spatial information about the nerve or its surrounding structures. Such information could help determine the etiology and may potentially aid in endoscopic procedures or in determining the cause of persistent symptoms postsurgically.[7–9]

Sonography and magnetic resonance imaging (MRI) have both been shown to be of value in the diagnosis of carpal tunnel syndrome.[10] The advantage of sonography and MRI over nerve conduction studies is that they provide structural information and identify alternative diagnoses such as rheumatoid arthritis tenosynovitis or synovitis of the wrist.[11] Nerve conduction studies and sonography have been shown to be complementary in the evaluation of carpal tunnel syndrome.[12] Compared to MRI, sonography has advantages of lower cost, portability, shorter examination times, and the possibility of sonographically guided intervention and treatment.[13] Furthermore, sonography has been shown to have even greater resolution for superficial structures, such as the carpal tunnel, compared to MRI.[14]

Studies have documented that a greater median nerve cross-sectional area at the wrist on sonography is correlated with abnormalities on nerve conduction studies consistent with carpal tunnel syndrome.[15] In addition to its use in diagnosis, sonographic testing is also responsive to changes after surgical intervention.[16] Several studies have attempted to determine the appropriate median nerve cross-sectional area cutoff value.[17] Variation exists with regard to the most appropriate median nerve cross-sectional area threshold for establishing the diagnosis of carpal tunnel syndrome.[18] A recent meta-analysis found heterogeneity for the specificity and likelihood of a positive test result with the use of sonography for the identification of carpal tunnel syndrome. This meta-analysis evaluated the threshold for the median cross-sectional area by grouping threshold values used in the studies identified for this analysis, with threshold areas ranging from 8.5 to 12.5 mm^2.[19]

Nerve conduction study parameters may vary with weight, height, and age; thus, these may be potentially relevant variables for sonographic measurements. Whether the difference in threshold values for sonographic carpal tunnel syndrome diagnosis stems from relevant subject factors needs to be further explored. Sonographic parameters do not appear to correlate with the severity of electrodiagnostic abnormalities in individuals with carpal tunnel syndrome.[20] Sonographic and electrodiagnostic studies have been done on healthy populations to establish normal values.[21,22] Prior studies have evaluated sonographic parameters compared to anthropometric measurements; however, the relationships between nerve conduction studies, sonographic measurements, and potentially relevant demographic and anthropometric data have received only limited study.[23] We hypothesized that sonographic parameters may be influenced by anthropometric measurements, similar to the relationship observed with nerve conduction studies; thus, associations may be found between observed differences between these sonographic measurements and nerve conduction studies. Studying these relationships may increase our understanding of when best to use these procedures and may help identify relevant sonographic variables, which may aid in improving the sensitivity and specificity in the diagnosis of carpal tunnel syndrome.[23]

Materials and Methods

Study Design

This study consisted of a prospective convenience sample of healthy adults and was conducted at the outpatient clinic of an urban academic medical center. Participants underwent screening followed by electrodiagnostic testing and sonographic examinations. All participants underwent median nerve motor and sensory nerve conduction studies using standard techniques.[21] A second examiner, who was blinded to the results of the nerve conduction studies, performed median nerve sonographic evaluations using a high-frequency linear array transducer. Local Institutional Review Board approval was obtained for this study, and all participants provided written consent.

Screening

Healthy adults (age ≥18 years) were recruited by word of mouth and recruitment flyers. Participants were screened for confounding medical or neurologic disorders by a medical history and a neurologic examination by the research physicians. Individuals were excluded for a medical history suggestive of a preexisting nerve disorder or a history of a medical condition (such as diabetes) that would predispose them to a nerve abnormality, as well as for abnormal physical examination findings. The physical examination included muscle strength testing, a sensory examination, and reflex testing of their upper limbs. Age, sex, and hand dominance were recorded. Height in meters and weight in kilograms were used to calculate the body mass index (BMI).

Electrodiagnostic Testing

All participants underwent standardized motor and sensory nerve conduction studies.[21] A Viking system (Nicolet Biomedical, Inc, Middleton, WI) was used. Disk electrodes were applied using Transpore tape (3M, Minneapolis, MN) using TECA electroconductive gel (Nicolet Biomedical, Inc). Skin surface temperatures were measured over the dorsum of the hand and maintained at or above 32°C.

The following equipment settings were used for motor studies: 5 mV/division; low-frequency filter, 2 to 3 Hz; high-frequency filter, 10 kHz; and sweep speed, 2 milliseconds/division. For median nerve motor studies, the active electrode was placed on the motor point of the abductor pollicis brevis (halfway between the midpoint of the distal wrist crease and the volar surface of the first metacarpal phalangeal joint. The reference electrode was slightly distal to the first metacarpal phalangeal joint, and the ground was placed on the dorsum of the hand.

Wrist stimulation was performed with the cathode 8 cm proximal to the active electrode on a line to the middle of the wrist crease and then proximally to the tendons of the flexor carpi radialis and palmaris longus. Elbow stimulation was performed slightly medial to the brachial pulse in the antecubital fossa. The measurements taken from the waveforms were as follows: onset latency at each site of stimulation and base-to-negative peak amplitude. Nerve conduction velocity was calculated as follows: (onset latency for proximal stimulation – onset latency for distal stimulation)/distance between the cathode sites for proximal and distal stimulation.

The following equipment settings were used for sensory studies: 20 μV/division; low-frequency filter, 20 Hz; high-frequency filter, 2 KHz; and sweep speed, 1 millisecond/division. For median nerve sensory studies, ring electrodes were used for the performance of antidromic studies. The ring electrodes were placed with the active electrode placed just proximal to the metacarpal phalangeal joint of the index finger and the reference electrode placed 4 cm distal to the active electrode. Surface stimulation was applied 14 cm proximal to the active ring electrode in the distal forearm between the tendons of the flexor carpi radialis and palmaris longus. The measurements taken from the sensory potentials were as follows: negative peak latency and peak-to-peak amplitude.

Sonography

An experienced physiatrist trained in performing sonography of the median nerve in the wrist and forearm, who was blinded to the results of the nerve conduction studies, performed the median nerve sonographic evaluations using a 10-MHz high-frequency linear array transducer (LOGIQ Book XP; GE Healthcare, Milwaukee, WI). The participants were seated facing the examiner. The participant's arm was extended at the elbow with the forearm supinated and the wrist resting on a hard flat surface in a neutral posture. The median nerve at the wrist was identified at the level of the distal volar wrist crease (carpal tunnel inlet) in the transverse plane and 4 cm proximally. The cross-sectional area of the median nerve at the wrist and 4 cm proximally in the forearm was measured on static images bilaterally by tracing the nerve margin at the junction of the hypoechoic nerve fascicles and adjacent outer connective tissue (Figure 1). Machine software was used to calculate the cross-sectional area from these traced images. The flattening ratio was calculated by measuring the major and minor axes of the nerve at the distal wrist site and calculating the ratio of the major axis to the minor axis.

Statistical Analyses

Means and associated 95% confidence intervals (CIs) summarize the sonographic measurements; we used paired *t* tests to compare cross-sectional area measurements by location (wrist or forearm) and dominant hand (yes or no). Nerve conduction measurements are summarized by means and standard deviations. The cross-sectional area of the median nerve at the wrist, cross-sectional area of the median nerve at the forearm, and wrist-to-forearm area ratio were evaluated for associations with weight, height, sex, and age. We used linear models and linear mixed models to estimate associations. For associations with multiple measurements from the same participant, we included a random intercept to account for correlation between measurements. Results are reported as estimated regression coefficients (95% CIs).

Because analyses indicated that the cross-sectional area differed significantly by the dominant hand, associations between physical characteristics and the cross-sectional area or flattening ratio controlled for the dominant hand by including the dominant hand in the regression model. When physical characteristics were significantly associated with the cross-sectional area or flattening ratio, we also estimated the association adjusted for the dominant hand, age, and sex by including these covariates in the model.

We also evaluated associations between the cross-sectional area and nerve conduction measurements (amplitudes, distal latencies, and conduction velocities) using linear models and linear mixed models with random intercepts. We estimated separate models for the dominant and nondominant hands.

Results

Fifty median nerves were evaluated in 25 adult participants (13 female and 12 male). The mean age of the participants ± SD was 32.6 ± 7.37 years, the median age was 30 years, and the age range was 26 to 54 years, although all but 3 participants were 36 years or younger. The demographic characteristics of the participants are reported in Table 1. There were 23 dominant right-handed participants and 2 dominant left-handed participants.

Summaries of the sonographic and nerve conduction results are reported in Tables 2 and 3, respectively. The mean wrist cross-sectional area in the dominant hand was 7.64 mm^2, and the area in the nondominant hand was 8.24 mm^2, which was not significantly different. The forearm cross-sectional area was significantly larger than the wrist area both for the dominant and nondominant hands. The forearm area was not significantly different between the dominant and nondominant hands. There was a statistically significant difference in the flattening ratio at the wrist for the right and left hands among right-handed participants only (estimated mean difference, 0.59; 95% CI, 0.09, 1.08).

Median Nerve Cross-sectional Area and Physical Characteristics

As summarized in Table 4, the wrist cross-sectional area was significantly associated with weight, whether adjusted for the dominant side or adjusted for the dominant side, age, and sex. The wrist area increased an average of 0.036 mm^2 (95% CI, 0.0067, 0.065 mm^2) for every 1-kg increase in weight. The wrist area was not significantly associated with height, age, or sex.

Forearm Cross-sectional Area and Physical Characteristics

The forearm cross-sectional area was significantly associated with height and weight (Table 4). The forearm area increased by an average of 0.076 mm^2 for every 1-kg increase in weight and 1.45 mm^2 for every 10-cm increase in height. The forearm area was not significantly associated with sex or age.

Flattening Ratio at the Wrist and Physical Characteristics

The flattening ratio at the wrist was not significantly associated with age, weight, height, or sex.

Figure 1. Transverse view of the median nerve at the volar distal wrist crease. The tracing outlines the median nerve in a cross-sectional view at the distal wrist crease.

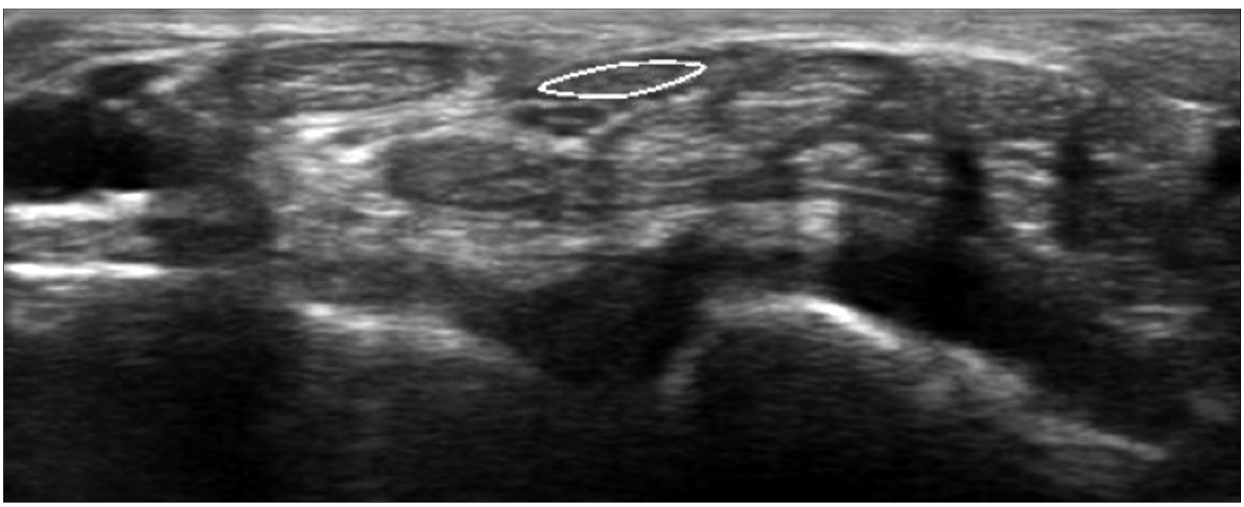


Table 1. Demographic Characteristics of the Participants

Characteristic	Value
Male	12 (48)
Female	13 (52)
Dominant hand	
Left	2 (8)
Right	23 (92)
Height, m	1.72 ± 0.11
Weight, kg	71.7 ± 17.68
BMI, kg/m^2	24 ± 3.62
Age, y	32.6 ± 7.37
Range	26–54
Median	30

Data are presented as number (percent) and mean ± SD where applicable.

Nerve Conduction and Sonographic Measurements

The compound muscle action potential amplitude with wrist stimulation was positively related to the cross-sectional area, with the area increasing by 0.195 mm^2 for every millivolt increase in amplitude in the dominant hand (95% CI, 0.020, 0.370 mm^2; $P < .05$) and 0.247 mm^2 in the nondominant hand (95% CI, 0.035, 0.459 mm^2; $P < .05$; Figure 2). In contrast, the sensory nerve action potential amplitude with wrist stimulation was inversely related to the cross-sectional area. For the dominant hand, for every millivolt increase in the sensory nerve action potential amplitude, the area decreased by 0.039 mm^2 (95% CI, –0.070, –0.008 mm^2; $P < .01$); for the nondominant hand, the decrease was 0.038 mm^2 (95% CI, –0.067, –0.009 mm^2; $P < .05$; Figure 3). For the nondominant hand, there was weak evidence for an association between the amplitude and the cross-sectional area. For every millivolt increase in amplitude, the area decreased by 0.000333 mm^2 (95% CI, 0.0000, 0.00067 mm^2; $P < .10$). There was no significant linear association between the wrist median cross-sectional area and median motor or sensory distal latencies for either the dominant or nondominant hands. Conduction velocity through the forearm was not significantly linearly associated with the forearm cross-sectional area or the forearm-to-wrist ratio (tapering ratio).

Discussion

This study found that weight influenced cross-sectional measurements of the median nerve distally at the wrist, and both height and weight influenced forearm measurements. In addition, we noted that median compound muscle action potential amplitudes increased with an increasing cross-sectional area on sonographic measurements of the median nerve at the wrist. In contrast, the median sensory nerve action potential amplitudes decreased as the wrist sonographic cross-sectional area increased. The flattening ratio appeared to be independent of anthropometric measurements; however, side-to-side differences may be relevant and should be a consideration when developing cutoff values for this sonographic measurement.

Limited studies have noted weak positive associations between height and the distal cross-sectional area of the median nerve and associations between height, weight, and

Table 2. Sonographic Measurements

Hand	Mean Wrist Cross-sectional Area, mm^2	Mean Forearm Cross-sectional Area, mm^2	Flattening Ratio at Wrist
Dominant	7.64 (6.91, 8.37)	9.64 (8.40, 10.88)	3.00 (2.38, 3.62)
Nondominant	8.24 (7.53, 8.95)	10.04 (8.88, 11.20)	2.50 (1.94, 3.06)

Values in parentheses are 95% CIs.

Table 3. Median Nerve Conduction Study Results

Study Type	Amplitude, µV (Sensory), mV (Motor)	Distal Latency, ms	Forearm Conduction Velocity, m/s
Sensory (index recording)			
Dominant hand	64.4 ± 21.7	3.1 ± 0.3	
Nondominant hand	66.6 ± 22.5	3.1 ± 0.3	
Motor			
Dominant hand	11.8 ± 3.9	3.4 ± 0.41	58.0 ± 3.7
Nondominant hand	10.9 ± 3.2	3.3 ± 0.37	59.0 ± 4.2

Data are presented as mean ± SD.

Table 4. Association of Nerve Cross-sectional Area With Weight and Height

Predictor	Additional Variables in Model	Regression Estimate	95% CI	*P*
Association With Wrist Cross-sectional Area				
Weight, kg	Dominant hand	0.036 mm^2 for every 1-kg increase in weight	0.0067, 0.065	<.05
Weight, kg	Dominant hand, age, sex	0.056 mm^2 for every 1-kg increase in weight	0.012, 0.100	<.05
Height, cm	Dominant hand	0.40 mm^2 for every 10-cm increase in height	–0.10, 0.90	>.05
Association With Forearm Cross-sectional Area				
Weight, kg	Dominant hand	0.076 mm^2 for every 1-kg increase in weight	0.026, 0.126	<.01
Weight, kg	Dominant hand, age, sex	0.091 mm^2 for every 1-kg increase in weight	0.016, 0.168	<.05
Height, cm	Dominant hand	1.45 mm^2 for every 10-cm increase in height	0.70, 2.19	<.01
Height, cm	Dominant hand, age, sex	1.70 mm^2 for every 10-cm increase in height	0.65, 2.74	<.01

BMI and the carpal tunnel cross-sectional area.[22] This study confirms prior findings that sonographic measurements are related to weight.[22] The findings that the cross-sectional area varies by weight and the forearm cross-sectional area varies by height and weight indicate that these parameters may be important to consider in the development of normative data for sonographic measurements. Tapering of the median nerve, as measured by the forearm-to-wrist cross-sectional area ratio, and conduction velocities were not found to be associated with anthropometric measures. This result is of interest, as greater tapering has been suggested as a factor in the finding that taller individuals have slower nerve conduction studies.[24] It is possible that we were unable to demonstrate this finding, however, because of the range of heights encountered for our study participants.

Slowing of conduction across the wrist is the most common parameter measured on nerve conduction studies for the diagnosis of carpal tunnel syndrome; however, amplitude has been used to evaluate for axonal loss and conduction blocks. In this study, although no significant association was found between the distal latencies and the sonographic cross-sectional area, amplitude is related to this sonographic measurement. Our finding that nerve conduction study amplitude parameters differ in their relationships for motor and sensory studies may be a reflection of the effect of weight on sonographic parameters and differences in the effect of weight on nerve conduction studies. Sensory nerve conduction study amplitudes have been found to decrease with an increasing digit circumference, whereas motor amplitudes do not.[25] It would be of interest

Figure 2. Linear mixed model cross-sectional area (CSA) versus compound muscle action potential (CMAP).

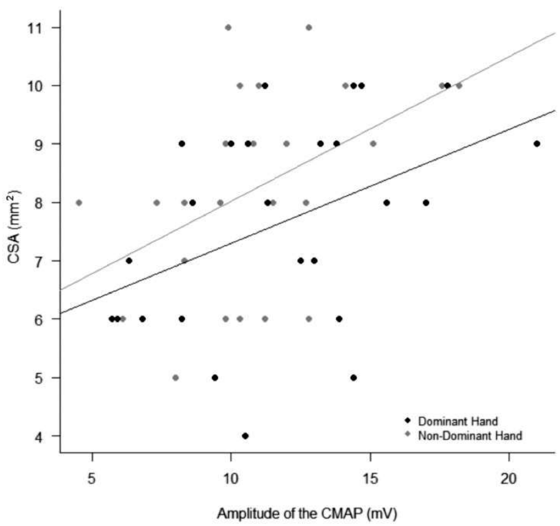
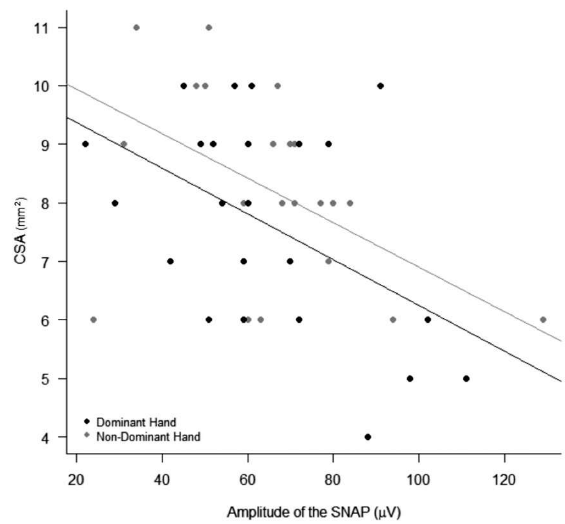


Figure 3. Linear mixed model cross-sectional area (CSA) versus sensory nerve action potential (SNAP).



to see whether this finding would be sustained in an population with abnormalities in which motor and sensory amplitudes deviate from standardized threshold values.

Previous studies have looked at swelling ratios in the diagnosis of carpal tunnel syndrome, as nerve entrapment often results in swelling of the median nerve just proximal to the site of entrapment.[26] Although studies have shown electrodiagnostics to be complementary to sonography in the diagnosis of carpal tunnel syndrome, particularly when the differential diagnosis involves cervical radiculopathy, peripheral polyneuropathy, sensory neuropathy, or a more proximal lesion involving the median nerve, sonography alone may be useful for diagnosing carpal tunnel syndrome.[27] Reported criteria differ, however, with parameters evaluated including an increase in the cross-sectional area of the median nerve at the level of the pisiform, an increase in the area at the pisiform compared to the area at the distal radius (swelling ratio), an increase in the flattening ratio of the median nerve at the level of the hook of the hamate, and, finally, the appearance of palmar bowing of the flexor retinaculum on sonography. The normal values cited for the mean cross-sectional area of the median nerve at the distal wrist have varied from 6.1 to 10.4 mm^2. Similar values were found in this study (7.64 mm^2 in the dominant hands and 8.24 mm^2 in the nondominant hands). Abnormal limits for the cross-sectional area have been cited as between 9 and 14 mm^2, and prior studies comparing electrodiagnostic tests and sonography have revealed a great range between the specificity and sensitivity of each.[19] These findings may in part be due to the failure to evaluate relevant parameters that may affect the results. Sonographic measurements do not appear to correlate strongly with the severity of electrodiagnostic abnormalities (mixed and motor nerve conduction study latency and amplitude) in individuals with carpal tunnel syndrome; thus, taking all relevant variables into account may increase the sensitivity for detection of such changes.[19]

It has been suggested that sonography cannot replace electrodiagnostic testing but can complement it.[28] Sonography has been used to show space-occupying lesions, which have resulted in carpal tunnel syndrome.[29] A recent evidence-based review concluded that sonography is accurate in the diagnosis of carpal tunnel syndrome and should be considered an alternative as a diagnostic test for this condition.[10] With further investigation and identification of normal and abnormal sonographic parameters and establishment of values based on all relevant physical examination parameters, sonography may well become the first line-test to confirm carpal tunnel syndrome.

Several study limitations warrant discussion. First, this study only examined healthy volunteers. As such, comparing healthy individuals to those with median nerve abnormalities such as carpal tunnel syndrome may show different relationships and may warrant further investigation in future studies. Second, only 2 participants were overweight, as determined by a BMI greater than 25 but less than 30 kg/m^2. Our sample was not a true representation of the demographic in the United States, and the findings of this study should be confirmed in further studies that include more individuals who would be categorized by BMI as overweight or obese. Sex did not affect the results of this study, and any observed differences would be more likely to be influenced by weight, which differs on average between men and women.

In conclusion, whereas associations were found between median nerve conduction study amplitudes and sonographic nerve measurements, they were not found for other parameters. Selected anthropometric measurements do affect sonographic measurements. Further study of these relationships may increase our understanding of when to best use and apply standardized measurement for these sonographic procedures.

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